# ASSESSMENT OF NEARSHORE SEDIMENT TRANSPORT ALONG COX'S BAZAR COAST USING DELFT3D MODEL


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# DECLARATION

I, Rehenuma Lazin hereby declare that the work presented in the thesis entitled "AASSESSMENT OF NEARSHORE SEDIMENT TRANSPORT ALONG COX'S BAZAR COAST USING DELFT3D MODEL", being submitted to Department of Water Resources Engineering, BUET for the degree of Bachelor of Science, is the outcome of the original work done by me under the supervision of Dr. Umme Kulsum Novera, Professor, Department of Water Resources Engineering, BUET. This work did not form part of any dissertation submitted for the award of any degree, diploma or other similar title or recognition from this or any other institution.

Rehenuma Lazin

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I am indebted to all the officials of the Institute of Water Modeling (IWM), for their help and cooperation in collecting the required data and information. I convey my deepest and sincerest regards to my family members for their understanding and moral support.

I am grateful to almighty Allah for giving me the strength to continue the study and bring it to the present stage.

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# ABSTRACT

Due to its unique geo-physical characteristics and vulnerability because of several natural disasters like erosion, cyclone, storm surges, tsunami, sea level rise, settlement and also various forms of pollution Bangladesh coastal area is different from any other part of the country. These natural hazards are increasing with high frequency and intensity along the coast of Bangladesh and adversely affected lives and livelihoods in the coastal zone and slowed down the pace of social and economic developments in this region. Water movement in the coastal zone of Bangladesh is determined by the wave coming from the Bay of Bengal and other meteorological conditions. A mathematical model study has been carried out to simulate the morphological changes in the nearshore coastline of the Cox's Bazar area in Bangladesh.

In this study a two dimensional hydrodynamic model Delft3D has been established based on different parameters like co-efficient of eddy viscosity, Manning roughness coefficient, advective and diffusion co-efficient etc .It has a number of modules for different purposes with different sets of equations.

The model output consists of wave height, wave velocity, sediment load at different grid point in the study area of Bay of Bengal. In this study erosion/deposition and changes in sediment load at different sections have been observed and simulated for different wave angle from offshore area. Simulated maximum wave height is verified at selected locations of coastal area with the measured maximum data. The output from the mathematical model Delft3D shown very good agreement with the measured data. These simulated results can be used for nearshore wave climate around the area. As a conclusion it can be said that the Delft3D model simulate reasonably sound output data for the selected domain of the nearshore zone of the Cox's Bazar area in Bangladesh.

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| | |
|---|---|
| BUET | Bangladesh University of Engineering and Technology |
| BWDB | Bangladesh Water Development Board |
| CEGIS | Centre for Environment and Geographic Information System |
| CPA | Chittagong Port Authority |
| DHI | Danish Hydraulic Institute |
| HD | Hydrodynamic |
| IWFM | Institute of Water and Flood Management |
| IWM | Institute of Water Modeling |

# Chapter 1

# Introduction

## 1.1 General

The coastal zone is a dynamic area comprising the natural boundary between land and ocean. In many countries of the world, the coastal zones have become the subject of major concern due to their multi-functional favorable uses. The intense uses of coastal zones, for building harbors, fisheries and recreational areas, utilizing food and mineral resources, energy procurement, industrial uses, providing water supply and so on, have make them multi-functional regions. However, the use of coastal zones is rather limited because of the existence of the wave actions, severe storm surges and tsunamis etc. Large-scale tsunamis and storm surges have occasionally flooded low-lying coastal areas and tremendous loss of life and property has been reported in various locations throughout the world.

Coastal Zone Policy 2005 defines that the coastal zone of Bangladesh consist of nineteen districts comprising one hundred and forty seven upazilas.  Among them a total of forty eight upazilas are the exposed coasts and the remaining ninety-nine upazilas are interior coasts.

## 1.2 Background of the study

There are many problems arising in Coastal zones. Disasters like cyclone, tide storm, drainage congestion, land erosion and drought that take toll on life and property and depletion of natural resource. In the coastal zone, agriculture continues to be a major source of employment, which is seasonal in nature. So reducing these disasters there has been a growing public concern with an increased awareness of different impacts on nearshore of coastal zone. Nearshore Hydrodynamic model has been used to calculate near-shore wave conditions based on offshore wave data. This work will be provided a framework in which a developer or contractor could quickly estimate near-shore wave conditions for a small section of coastline, using existing offshore wave data and without running complicated global wave models.

## 1.3 Mathematical model used for this study

In order to study the behavior of The Bay of Bengal at Cox's Bazar coast, application of 2D (Two dimensional) model in the Cox's Bazar coast is inevitable. This study focuses mainly on the application of 2D model Delft3D to assess different wave and morphological behavior of nearshore at Cox's Bazar. Delft3D is composed of different modules, for this research Delft3D flow and wave module is used for simulating and determining different hydrodynamic and morphological parameters.

## 1.4 Scope and Importance of Mathematical modeling

The wish to improve the safety situation and to foresee the impact of the ever growing human interference with the environment, has created a need for reliable predictions of complex situations found in nature. The socio economic and political importance of alluvial systems has also increased this need. In early time, research methodologies of wave processes were primarily based on field observation and laboratory scale modeling. Laboratory scale models and field measurements have been and are still essential for the understanding of complex wave processes, and are used as design and verification tools, despite their high cost of construction, maintenance and operation. An alternative that has been growing in popularity and acceptance is r modeling. Wave modeling is the analysis and simulation of flow conditions based on the formulation and solution of mathematical relationships expressing hydraulic principles. Mathematical modeling has become a very useful tool for understanding and predicting the natural phenomenon. It allows to interpret sophisticated situation in an easier and integrated way. Even though the model results may not be reliable, so every model requires some sort calibration with the observed data so that it may not mislead towards wrong decision. The type of model used depends on the purpose of the research or project, Hydrological model is used when it is required to formulate hydrological processes such as precipitation, snow melt, interception, evapotranspiration, infiltration, sub-surface flow and surface flow as well as interaction between them. On the other hand Hydraulic model is used when it is required to formulate flows, sediment transports, waves, water quality, morphological developments, ecology and other processes. In this study wave and morphological behavior of Bay of Bengal at Cox's Bazar has been examined using Delft3D.

## 1.5 Objective of the study

Delft3D allows us to obtain lots of hydrodynamic and morphological parameters from the simulation. The features which will be focused in this study are as following

- To apply Delft3D morphological model to simulate wave model in the Bay of Bengal at Cox's Bazar coast.
- To assess morphological changes due to wave action.
- To quantify the erosion/deposition impact on the selected area of interest and determine sediment budget in order to find out the deficit or excess of sediment load.

The output of the present study will help to improve the understanding of the wave processes. The finite difference model developed is calibrated using computed values and values obtained from the field. The outcome of simulation will give an idea of how the velocity, sediment transport and bed level are changing due wave action.

## 1.6 Organization of the report:

**Chapter 1:**

This chapter of this study gives a brief description of the total research work along with the objective of this research. It also gives a short description of importance of mathematical modeling tools for analyzing wave and morphological behavior of Cox's Bazar coast.

**Chapter 2:**

In this chapter a short description of Cox's Bazar coast is given. Several studies undertaken previously on this coast and some coastal studies are described here in brief. Different numerical models used all over the world are also depicted in this chapter.

**Chapter 3:**

This chapter mainly deals with theories of wave and the model Delft3D. Different modules/tools and their uses are described here. A detailed description of numerical methods used and their function are elaborated in this chapter.

This chapter also deals with the development of the model for this study. The logical development of the model has been briefly presented. Hydrodynamic calibration is

presented here. A comparison of morphological behavior of the model against the observed data is made in this chapter.

**Chapter 4:**

This chapter comprises the results of model simulation and comparison between different scenarios. A detail analysis of morphological behavior of the area of interest is made in this chapter.

**Chapter 5:**

This is the final chapter of this dissertation which draws the conclusion of the study along with few recommendations for further research and development.

# Chapter 2

# Literature Review

## 2.1 General

The 86 km long shark free sandy beach between Cox's bazar and Teknaf within the latitude 20°44.7'N and 21 °24.30'N and longitude 92°20.12'E and 91 °57.88'E is considered as the most important part of Bangladesh coast. Hydrodynamic process of this coastal zone changes season to season and due to mane natural hazards. Many numerical modeling studies have been carried out on the coastal area of Bangladesh as well as different coastal areas in the World to understand the impact of various events like: Generation of waves, waves induce generation circulations, climate change induced SLR, storm -surge, tide -surge interaction etc. Several different coastal processes studies regarding coastal zone of Bangladesh as well as of the world are reviewed in this chapter.

## 2.2 Coastal Area of Bangladesh

The coastline of Bangladesh can be described under two major groups resulting from different geological processes. These two groups also conform to different physiographic descriptions. The first group having a near east-west orientation, extends from Haribanga channel along Indo-Bangladesh border in the west to the Sandwip channel in the east and covers a coastline of about 380 km (Barua 1991). The second group is the entire 275 km coastline of Chittagong and Cox's bazar which has a north-south orientation. The coastal plain of Chittagong and Cox's bazar can further be sub-divided into two separate hydromorphological units. The 230 km coastline from Naf river in the south to Karnaphuli river in the north can be described as a wave dominated sand coast and 45 km coast from Karnaphuli river in the south and Sandwip channel in the north can be described as an estuarine mud coast. The 230 km coast line lies between the latitude 20°44.7'N and 22°16.0'N and longitude 92°20.12'E and 91 °57.88'E and are characterized by the sandy beaches at Chittagong, Banskhali, Cox's Bazar, Ukhia and Teknaf and the Matamuhuri delta and Coastal Islands between Banskhali and Cox's Bazar. This coastline is interrupted by the four major rivers namely Karnaphuli, Sangu, Moheskhali channel, Bagkhali and the Naf river. Some small streams coming from the hills adjacent to the east of the coast

are also present. The sandy beaches at Chittagong extends between Patenga at the north and upto Banskhali at the south. The sandy beaches at Cox's bazar extends between the Bagkhali river at the north and upto the Naf river at Teknaf through Ukhia and Nhila. A huge land has been accreted at Badarmokkam at the confluence of the Naf river with the Bay of Bengal.

## 2.3 Previous Studies on The Bay of Bengal along Cox’s Bazar

Lewis el at. (2013) studied that a computationally inexpensive inundation model has been developed from freely available data sources for the northern Bay of Bengal region to estimate flood risk from storm surges. The main aim of this paper is to develop a LISFLOOD-FP inundation model of the northern Bay of Bengal based on only freely available data sources and test the model against maximum water level observations taken during the 2007 " Sidr" even using parameters from two cyclone databases (IBTrACs and UNISYS).

Barua el at. (1995) studied that the majority of the coastline of Bangladesh represents the margin of a deltaic plain which is located at the head of the Bay of Bengal. This paper is presented in three sections. First is an analysis of the wind field from which wave hind casts are derived. Secondly, we have used a finite element refraction model developed by Coastal Science & Engineering to see the convergence and divergence of wave energies. This section also contains computations of wave refraction by tidal currents. The third section deals with some estimates on wind and wave induced transport and provides a qualitative analysis of the morphological consequences resulting from them.

Hossain (2001) studied that Bangladesh is a vast delta bounded by the Bay of Bengal on its southern limit. The landmass is mostly flood plain in origin, with most of the territory only a few meters above sea level except a portion of hilly lands in the north and south.

Lewis el at. (2014) studied that coastal flood risk from tropical cyclone storm surge is high in the northern Bay of Bengal and projected to increase with sea level rise. Accurate estimates of storm surge magnitude and frequency are essential to coastal flood risk

studies. Several hydrodynamic models have been developed to simulate storm surges in the region.

Islam el at. (2009) studied that Bangladesh has been 710 km long coast to the Bay of Bengal which contains several ecosystems that have important conservation values. This paper represents the overall current situation of two Integrated Coastal Zone Management (ICZM) programs- one is as a successful model like Xiamen ICZM program in China and another is as a developing project like ICZM program in Bangladesh.

Sarwar (2005) studied on the Impacts of sea level rise on the coastal zone of Bangladesh. The study revealed that a one meter sea level rise will affect the vast coastal area and flood plain zone of Bangladesh.

Jain el at. (2010) studied that coastal regions of the east coast of India are very vulnerable to severe flooding due to storm surges associated with intense tropical cyclones originating in the Bay of Bengal. Wind is the main generating mechanism of storm surges, and a rise sea level. The tides augment the storm surges and resulting water levels enhanced significantly.

Sayma and Salehin (2012) assessed salinity constraints to different water uses in coastal area of Bangladesh. It was an attempt to delineate the salinity related problems on multi-purpose uses of water and assess better water management options in a small scale water resources subproject in south-west coastal region of Bangladesh.

## 2.4 Studies on Coastline Hydrodynamics around the World

FaInes (2007) Studied, comparing ocean-wave energy with its origin, wind energy, the former is more persistent and spatially concentrated. The global power potential represented by waves that hit all coasts worldwide, has been estimated to be in the order of 1TW (1 terawatt 10I2W). If wave energy is harvested on open oceans, energy that is otherwise lost in friction and wave breaking, may be utilized.

Folley (2009) studied that analysis of the nearshore wave energy resource. When wave energy began to be taken seriously as a potential source of renewable energy, the majority of wave energy converters (WEC's) have been conceived as offshore devices, where the highest wave energy densities was found. The gross nearshore wave energy resource is significantly smaller than the gross offshore wave energy resource implying that the deployment of wave energy converters in the nearshore is unlikely to be economic.

Hiles (2007) studied that a Computational models for wave climate assessment in support of the wave energy industry. This thesis identifies, and where necessary develops, appropriate methods and procedures for using nearshore wave modelling software to provide critical wave climate data to the wave energy industry. The nearshore computational wave modelling packages SWAN and REF/DIF were employed to estimate wave conditions near-shore. These models calculate wave conditions based on the offshore

Mandal, and Kumar, (2003) studied on the topics of estimation of wind speed and wave height during cyclones. They related wave and wind characteristics based on the cyclones, in the vicinity of the Nagapattinam coastline (east coast of India). They also estimated the maximum significant wave height for all the cyclones within the storm and its associated spectral peak period using the Young's model.

## 2.5 Numerical Methods

There are different techniques available for the solution of numerical problem; five of the major techniques (Huyakorn and Pinder, 1983) available are finite difference methods, Galarkin or variational finite element methods, collocation method, method of characteristics and boundary element methods. All these methods are closely related .In many cases the finite element, finite difference and collocation methods yield the same approximation. In the boundary element method, a variant of conventional finite element method is especially useful in the solution of elliptic equation for which green’s functions exist.

### 2.5.1 Finite Difference Method

Finite difference method is relatively straightforward. Finite difference method (Remeson 1971), with explicit, implicit or mixed difference schemes, belong to the most frequently used techniques in the modeling of groundwater flow. The fundamental idea is to replace all derivatives by finite difference and thus reduce the original continuous boundary value problem to a discrete set of simultaneous algebraic equation. The advantage of this method is in its simplicity and efficiency in treating the time derivatives. This model is not capable to deal with complex geometries of flow regions. A slow convergence, a restriction bilinear grids and difficulties in treating moving boundary conditions are other serious drawbacks of the method.

Finite difference method has been used in many studies solving one-dimensional (vertical) , variably saturated flow problems (e.g. Whisler and Watson, 1968; Brandt et al.,1977 ; Dane and Mathis , 1981 ; Haverkamp and Vauclin , 1981). Fewer researchers have attempted finite differences to solve variably saturated flow problems in higher dimensions (e.g. Cooley,1981; Freeze, 1971; Healy et al., 1990; Kirkland et al, 1992) presented an efficient algorithm of a finite difference solution to two dimensional, variably saturated flow problems.

### 2.5.2 Finite Element Method

It is extremely flexible method which can easily handle irregularly shaped flow regions. In finite element method the domain is divided into a number of grid elements. Each element is characterized by local coordinate functions. Partial differential equation is transformed into integral equation which includes derivatives of the first order only. Then integration is performed numerically over elements into which the considered domain is

Finite element is a numerical procedure for solving differential equations encountered in science and technology. Several researchers conducted their researches to solve their problems using finite element method (Neuman, 1973; Javandel and Witherspoon 1968).

## 2.6 Various Hydrodynamic and Sediment Transport Model

Different kinds of 1-D, 2-D and 3-D hydrodynamic and sediment transport models are in use in water engineering sector. Some of the widely used models are briefly summarized as below:

HEC Model Series, including HEC-UNET, HEC-6, and HEC-RAS is a set of one-dimensional models of hydrodynamics and sediment transport provided by the U.S. Army Corps of Engineers.

MIKE Model series together comprises a set of finite difference models in 1D, 2D and 3D. Most of the MIKE models (Mike-11, MIKE-12, and MIKE-3) which use rectangular, potentially nested grid. Modules exist to cover hydrodynamics, sediment transport, water quality, and wave generation/ transformation. MIKE-21C uses curvilinear grid.

CH2D/CH3D are two three dimensional finite difference models of hydrodynamics, salinity and sediment transport. These models use a curvilinear orthogonal grid. CH2D/CH3D are developed and maintained by the U.S. Army Corps of Engineers. This software is not freely available to users outside the U.S. Army Corps of Engineers. Model development and application are possible through a cooperative agreement with the Waterways Experiment Section or other branches within the Corps.

TELEMAC Model Series comprises a set of two and three dimensional finite element models of hydrodynamics, with Modelling of salinity provided by WQ-2D and WQ-3D, and sediment transport by SUBIEF. The models use irregular triangular grids. TELEMAC and the associated models are commercially available from H.R. Wallingford, U.K.

GEMSS consists of a three-dimensional finite difference hydrodynamic, water quality and sediment transport model with a curvilinear orthogonal grid. The model uses the same basic hydrodynamic model (GLLVHT) as CE-QUAL-W2. The model is developed by J.D. Edinger Associates. Model development and application are possible only through a cooperative agreement with the developers.

ADCIRC is a two and three dimensional finite element hydrodynamics model using an irregular grid and provided by the U.S. Army Corps of Engineers. ADCIRC is supported by the SMS preprocessing and display suite.

RMA Model Series, together with the SED-2D model, is a set of one, two and three dimensional models of hydrodynamics, sediment transport and water quality. The RMA models are finite element models. This model can be run with 1-D elements, has significant computational efficiency. It has the capability of addressing certain control structures, but not all the structures envisioned for the ponds. The models are in the public domain. RMA is supported by the SMS preprocessing and display suit.

SMS is a one-, two- and three dimensional hydrodynamic Modelling. SMS is used as a pre- and post-processor for surface water modelling, analysis and design. It includes tools for managing, editing and visualizing geometric and hydraulic data and creating, editing and formatting mash/grid for use in numerical analysis.

SOBEK is a powerful modeling framework for flood forecasting, modeling of drainage systems, control of irrigation systems, sewer overflow design, river morphology, salt intrusion and surface water quality. The components within the SOBEK modeling framework simulate the complex flows and water related processes in an accurate way in one dimensional (1D) network systems on two dimensional (2D) horizontal grids. It is the ideal tool for guiding the designer in making optimum use of resources.

The Delft3d Modeling system, developed by Delft Hydraulics. It is used to simulate hydrodynamic processes due to waves, tides, rivers, winds and coastal currents. Hydrodynamic flow is simulated with the flow module (WL Delft Hydraulics, 2001), which solves unsteady shallow water equations in two (depth-averaged) or three dimensions. The wave computation uses flow characteristics from a completed Delft3D-FLOW computation. The Delft3D can be run in Cartesian (equidistant or stretched) or curvilinear coordinates; all necessary grid generation software for creating curvilinear grid is included with the Delft3D package.

As mathematical models have their limitations, they cannot stand alone. Results should be assessed critically against field/laboratory data to assure that misleading conclusions are not drawn from a poorly designed and calibrated mathematical model.

## 2.7 Summary

In this chapter a brief description of Bangladesh coastal area, previous studies on the Bay of Bengal, coastal studies around the world and different mathematical models are represented. As coastal area of Bangladesh is low lying and exposed to the sea. They are more vulnerable to wave induced velocity action that causes more erosion and accretion than that of other land areas. That is why the main focus of the study to assess the value of nearshore wave height, wave celerity and wave angle from deep water wave condition by using Delft3D numerical model at several locations in the coastal zone of Cox's Bazar of Bay of Bengal of Bangladesh.

Being the longest beach in the world, variation of various wave properties in different climatic condition, generation of waves**,** morphological changes can be observed more explicitly in Cox's Bazar coastline. The ease of distinct observation initiates to choose Cox's Bazar as the study area.

# Chapter-3

# Theory and Methodology

## 3.1 General

The prediction technique of wave velocity , wave height and morphological changes in the study area due to wave action using numerical methods through mathematical model has been represented in this chapter. The mathematical model has been set up using the bathymetry of the Bay of Bengal along the Cox's Bazar. This model has been based on the FORTRAN Program. Numerical model has a number of modules for different purposes and each module deals with different sets of equations. In this study "wave" of the Numerical model has been used to simulate hydrodynamics parameters in the nearshore coast of Cox's Bazar of the Bay of Bengal. Concept of wave and wave theory, different methods of solving partial differential equations (analytical and numerical) are illustrated thereof. A short description of Numerical model, bathymetry generation, development of Bay of Bengal model with the governing equations of wave of Numerical model and key stages of model development have been illustrated in the following section.

## 3.2 Theory

### 3.2.1. Wave

Wave is an oscillating movement up and down, of a body- of water caused by the frictional drag of the wind. It is a form of energy without any mass. Waves carry energy but they do not transfer matter.

Nearshore hydrodynamics is the study of liquids in motion. It describes the characteristics of wave, tide, pressure etc. The ability to accurately predict wave process from deep to shallow water is vital to an understanding of coastal processes. Wave propagates towards the shore, a combination of shoaling, refraction and diffraction processes effect and modify the deep water wave. Wave model applicability depends not only on the size of the area of the model but also the dominant physical processes affecting wave evolution in that area, including those defined in:

**1. Wave generation by wind:** the development of surface gravity waves caused by the transfer of energy from wind to the ocean surface.

**2. Shoaling:** an effect whereby wavelength decreases and wave height increases due to a decrease in water depth.

**3. Refraction:** a turning of wave fronts toward shallower water due to phase speed dependence on water depth. in shallow water, refraction tends to line up wave fronts so that they parallel bathymetric contours:

**4. Diffraction:** a process which spreads wave energy laterally, orthogonal to the propagation direction, that occurs when waves encounter obstacles whose radius of curvature is comparable to the wavelength of the incident waves.

**5. Reflection:** a change in direction of a wave front resulting from a collision with a solid obstacle.

**6. Bottom friction:** a mechanism that transfers energy and momentum from the orbital motion of the water particles to a turbulent boundary layer at the sea bottom;

**7. Energy dissipation wave breaking due to:** a loss of wave energy due to the turbulent mixing which occurs when wave steepness surpasses a critical level causing water to spill off the top of a wave crest.

**8. Wave-wave interactions:** (triad) two propagating waves exchange energy with a third wave, (quadruplet) four propagating waves exchange energy with one-another.

**9. Wave-current interactions:** encompasses changes in wave amplitude due to shoaling (caused by current related change in propagation speed). Change in frequency due to the Doppler effect and change in direction due to current induced refraction.

### 3.2.2. Types of waves

It may divide into two sections:

**Regular Waves**

The waves are constant in height and period. It is the simplest mathematical representation assuming ocean waves are two-dimensional (2-D), small in amplitude, sinusoidal, and progressively definable by their wave height and period in a given water depth.

**Irregular Waves:**

In the Irregular Waves, the waves may have differing periods and heights. It is a complete 3-D representation of ocean waves requires considering the Irregular Waves: In the Irregular Waves, the waves may have differing periods and heights. It is a complete 3-D representation of ocean waves requires considering the sea surface as an irregular wave train with random characteristics.

### 3.2.3. Wave Theories

There are two well established theories to describe wave motion. One is known as Airy theory (1845) and other is Stoke's theory (1880). The simplest wave theory is the first-order, small-amplitude, or Airy wave theory which will hereafter he called linear theory. Many engineering problems can be handled with ease and reasonable accuracy by this theory. From theoretical point of view Stoke's theory is better than Airy theory, but is very complex. The Airy theory is relatively simple but the results differ from Stoke's theory for small depths and large wave heights

### 3.2.4. Definition of wave parameters

A simple, periodic wave of permanent form propagating over a horizontal bottom may be completely characterized by the wave height H, wavelength L and water depth d, shown in the definition sketch (Figure:3.1).

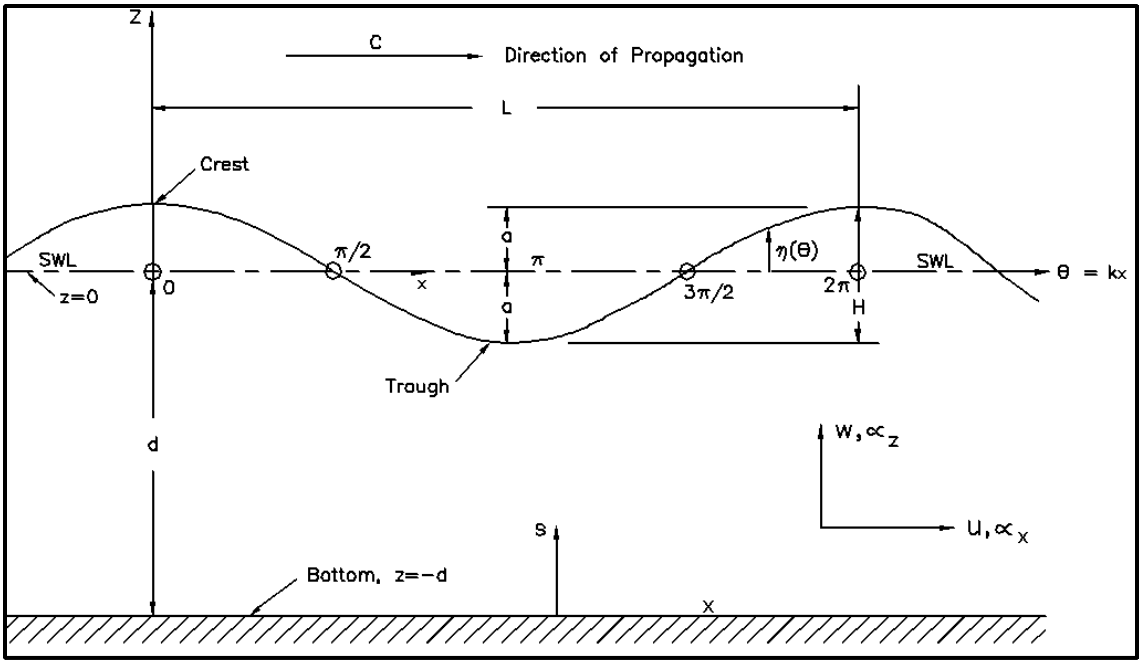


Figure 3.1: Schematic diagram of a regular wave (Source: CEM 2002)

**Wave crest**: It is the section of a wave profile where the water reaches its greatest height. It is a convex upward shape and the curvature is determined by many factors.

**Wave trough**: It is the section of a wave profile where the water is at its lowest level. It is concave upwards or may even appear horizontal over a reasonable length of the wave.

**Wave height (H):** It is the vertical distance from the crest level to the trough level. In a simple series of waves the height of each wave remains the same.

**Wave amplitude (a):** It is the height of the crest above the still-water level (SWL) and the distance of the trough below the SWL are each equal to the wave amplitude. Therefore, a = H/2,

**Wave length (L):** It is the horizontal distance between two identical points on two successive wave crests or two successive wave troughs.

**Wave period (T):** It is the time for two successive crests or troughs to pass one point on the water surface. It is the one characteristics of a wave that remains constant at all times, no matter what changes occur in height or length. The period is normally expressed in seconds.

**Wave frequency (f):** It is the reciprocal of the wave period and represents the number of waves passing a location in some unit of time (generally in 1 second). **Wave celerity (C):** It is the velocity at which a wave travels across a liquid surface, so that by definition:

$C=\frac{L}{T}$

Other wave parameters include

Angular or radian frequency, $w = \frac{2\pi}{T}$

Wave number, $k = \frac{2\pi}{L}$

Wave steepness, $\varepsilon= \frac{H}{L}$

Relative depth, $\frac{d}{L}$

Relative wave height, $\frac{H}{d}$

These are the most common parameters encountered in coastal practice. Wave motion can be defined in terms of dimensionless parameters H/L, H/d, and d/L

**Deep water waves:**

If the relative depth (d/L) is equal to or greater than 1/2 then the wave is called deep water wave or short waves. In deep water waves, the orbits of the particles are circular, the radius of which is one half the wave height about its normal center, midway between the crest and the trough.

**Shallow water waves:**

If the relative depth (d/L) is less than 1/20 then the depth is small in comparison with the wave length and the wave is termed as "shallow water wave" or "long wave". In shallow water waves the particle orbits are elliptical in shape as shown in figure. Tidal waves are shallow water waves.

### 3.2.5. Calculation of the deep water wave to the shallow water wave

The wave height and wave period at deep shore is determined by using the following formulas

$\frac{gH_{mo}}{U_{a^2}}$=1.60×10$^{-3}$ ($\frac{gF}{U_{a^2}}$)$^{1/2}$ ………………………… (3.1)

$\frac{gT_m}{U_a}$=2.857×10$^{-1}$ ($\frac{gF}{U_{a^2}}$)$^{1/3}$ ………………………… (3.2)

g = Acceleration due to gravity

$H_{mo}$--- Wave height in deep shore

$T_m$= Wave period corresponding to the wave height at deep shore

$U_a$= velocity (monthly maximum wind velocity) Corresponding fetch length

In deep water,

Celerity, Co = 1.56T ……………………………………..(3.3)

Wave length, Lo =1.56T2 ……………………………………..(3.4)

In shallow water,

Celerity , C=$\frac{gT}{2\pi}$ tanh $\frac{2\pi d}{L}$ ……………………………(3.5)

Wave length

L=$\frac{gT^2}{2\pi}$ tanh $\frac{2\pi d}{L}$ …………………………….(3.6)

The group velocity,

$C_{go}$ = 1/$C_o$ ……………………………….(3.7)

The group velocity in deep water,

$C_g$=nC ........................................... (3.8)

Where n= $\left(1+\frac{\frac{4\pi d}{L}}{sinh\frac{4\pi d}{L}}\right)$ …………………............. (3.9)

Waves are affected by the depth, they changes as they begin to feel the bottom. Only the period remains constant. In order to be effected by the bottom the depth has to be

approximately less than half of the wavelength. As waves move towards shallow waters, they will be refracted, causing a change in the direction of propagation. Refraction occurs since waves in deeper water moves faster than waves in shallow waters.

This can be shown by Snell's law:

$$\frac{H}{H_o} = \sqrt{\frac{Cg_o}{Cg}} = \sqrt{\frac{\cos\Theta}{\cos\Theta_o}} \text{ ..........................................} \quad (3.10)$$

where, $\Theta_o$ is the angle between a wave front and a local isobaths (a line of constant depth) for the deeper part and $\Theta$ for the shallower part, $H_o$ is the depth in deep water. $C_g$ is the group velocity for the shallower part and $C_{go}$ is the group velocity for the deep water.

Equation (10) can be written as

$$H = H_o K_s K_r \text{ ............................................} \quad (3.11)$$

$K_s$ is called the shoaling coefficient and

$K_r$ is the refraction coefficient.

Finally, H is the wave height for the shallow water and by transferring from point to point i.e. from deep water to shallow water; we obtain the wave height at near shore.

## 3.3 Background of the Model Delft3D

### 3.3.1 General

The current study applies a process-based model (Delft3D). The model numerically solves the shallow water equations, so that water levels and velocities are described in the modeled area at any time and at any place in the grid. These data are used to predict the associated sediment transport. The change of the bathymetry is subsequently calculated from the divergence of the sediment transport field in the area. Thus, the morphodynamic development originates from evolving interactions between flow and bed level development. Flow characteristics shape the bed and bed level developments, in their turn, direct the flow.

### 3.3.2 Different Modules and Utilities

Delft3D is a 3D modeling suite to investigate hydrodynamics, sediment transport and morphology and water quality for fluvial, estuarine and coastal environments. As per 1 January 2011, the Delft3D flow (FLOW), morphology (MOR) and waves (WAVE) modules are available in open source. The FLOW module is the heart of Delft3D and is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation programme which calculates non-steady flow and transport phenomena resulting from tidal and meteorological forcing on a curvilinear, boundary fitted grid or sperical coordinates. In 3D simulations, the vertical grid is defined following the so-called sigma co-ordinate approach or Z-layer approach. The MOR module computes sediment transport (both suspended and bed total load) and morphological changes for an arbitrary number of cohesive and non-cohesive fractions. Both currents and waves act as driving forces and a wide variety of transport formulas have been incorporated.

For the suspended load this module connects to the 2D or 3D advection-diffusion solver of the FLOW module; density effects may be taken into account. An essential feature of the MOR module is the dynamic feedback with the FLOW and WAVE modules, which allow the flows and waves to adjust themselves to the local bathymetry and allows for simulations on any time scale from days (storm impact) to centuries (system dynamics). It can keep track of the bed composition to build up a stratigraphic record. The MOR module may be extended to include extensive features to simulate dredging and dumping scenarios. Delft3D also have some other modules and utilities which are described below.

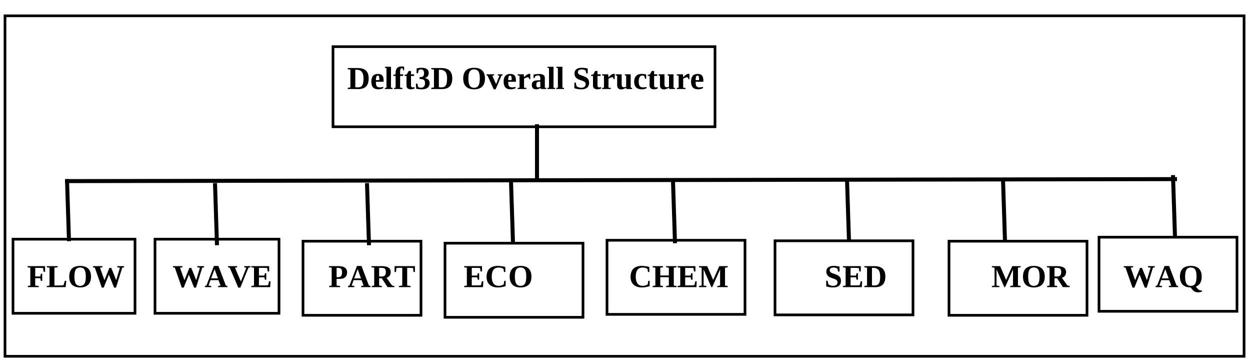


Figure 3.2: Overall structure of Delft3D

Delft3D WAVE - short wave propagation

Delft3D-WAQ - far-field water quality

Delft3D-PART - mid-field water quality and particle tracking

Delft3D-ECO - ecological modelling

Delft3D-SED - cohesive and non-cohesive sediment transport

Delft3D-RGFGRID - for generating curvilinear grids

Delft3D-QUICKIN - for preparing and manipulating grid oriented data, such as bathymetry or initial conditions for water levels, salinity or concentrations of constituents

Delft3D-TRIANA - for performing on-line tidal analysis of time series generated by Delft3D-FLOW

Delft3D TIDE - for performing tidal analysis on time-series of measured water levels or velocities

Delft3D-NESTHD - for generating (online) boundary conditions from an overall model for a nested mode

Delft3D-GPP - for visualization and animation of simulation results

Delft3D-QUICKPLOT - a second tool for visualization and animation of simulation results

### 3.3.3 Properties of the Computational Model

The computational model Delft3D-FLOW can be characterised by means of the following distinguished properties:

Grid alignment with complicated boundaries and local grid refinements to meet the needs of resolving finer spatial resolution in various numerical modelling tasks, which results in an accurate description of geometry

Application for one- and two-dimensional vertically averaged as well as hydro-static or non-hydrostatic three-dimensional problems

A solution technique that allows for solution based on accuracy considerations rather than stability (alternating direction implicit finite difference method)

Conservation of fluid and tracer mass locally and globally;

Computationally efficient and robust;

A computational core and a separate user interface.

Efficient coupling with other physical processes via the other modules of the integrated

### 3.3.4 Assumptions underlying Delft3D-FLOW

In Delft3D-FLOW the 2D (depth-averaged) or 3D non-linear shallow water equations are solved. These equations are derived from the three dimensional Navier-Stokes equations for incompressible free surface flow. The following assumptions (WL, Delft Hydraulics, 2005a) and approximations are applied:

In the c co-ordinate system the depth is assumed to be much smaller than the horizontal length scale. For such a small aspect ratio the shallow water assumption is valid, which means that the vertical momentum equation is reduced to the hydrostatic pressure relation. Thus, vertical accelerations are assumed to be small compared to the gravitational acceleration and are therefore not taken into account. When this assumption is not valid then Delft3D provides an option to apply the so-called Non-hydrostatic pressure model in the Z-model. For details, we refer to Chapter 12 of this User Manual.

The effect of variable density is only taken into account in the pressure term (Boussinesq approximation).

In the o co-ordinate system, the immediate effect of buoyancy on the vertical flow is not considered. In Delft3D-FLFLOW vertical density differences are taken into account in the horizontal pressure gradients and in the vertical turbu-lent exchange coefficients. So the application of Delft3D-FLFLOW is restricted to mid-field and far-field dispersion simulations of discharged water.

For a dynamic online coupling between morphological changes and flow the 3D sediment and morphology Add-on is available.

In a Cartesian frame of reference, the effect of the Earth's curvature is not taken into account. Furthermore, the Coriolis parameter is assumed to be uniform unless specifically specified otherwise.

In spherical co-ordinates the inertial frequency depends on the latitude.

At the bottom a slip boundary condition is assumed, a quadratic bottom stress formulation is applied.

The formulation for the enhanced bed shear-stress due to the combination of waves and currents is based on a 2D flow field, generated from the velocity near the bed using a logarithmic approximation.

The equations of DeIft3D-FLFLOW are capable of resolving the turbulent scales (large eddy simulation), but usually the hydrodynamic grids are too coarse to resolve the fluctuations. Therefore, the basic equations are Reynolds-averaged introducing so-called Reynolds stresses. These stresses are related to the Reynolds-averaged flow quantities by a turbulence closure model.

In Delft3D-FLFLOW the 3D turbulent eddies are bounded by the water depth. Their contribution to the vertical exchange of horizontal momentum and mass is modelled through a vertical eddy viscosity and eddy diffusivity coefficient (eddy viscosity concept). The coefficients are assumed to be proportional to a velocity scale and a length scale. The coefficients may be specified (constant) or computed by means of an algebraic, k-L or k-" turbulence model, where k is the turbulent kinetic energy, L is the mixing length and " is the dissipation rate of turbulent kinetic energy.

In agreement with the aspect ratio for shallow water flow, the production of turbulence is based on the vertical (and not the horizontal) gradients of the horizontal flow . In case of small-scale flow (partial slip along closed boundaries), the horizontal gradients are included in the production term.

The boundary conditions for the turbulent kinetic energy and energy dissipation at the free surface and bottom assume a logarithmic law of the wall (local equilibrium).

The eddy viscosity is an-isotropic. The horizontal eddy viscosity and diffusivity coefficients should combine both the effect of the 3D turbulent eddies and the horizontal motions that cannot be resolved by the horizontal grid. The horizontal eddy viscosity is generally much larger than the vertical eddy viscosity.

For large-scale flow simulations, the tangential shear-stress at lateral closed boundaries can be neglected (free slip). In case of small-scale flow partial slip is applied along closed boundaries.

For large-scale flow simulations, the horizontal viscosity terms are reduced to a bi harmonic operator along co-ordinate lines. In case of small-scale flow the complete Reynold's stress tensor is computed. The shear-stress at the side walls is calculated using a logarithmic law of the wall.

In the co-ordinate system, Delft3D-FLFLOW solves the so-called long wave equation. The pressure is hydrostatic and the model is not capable of resolving the scales of short waves. Therefore, the basic equations are averaged in analogy with turbulence introducing so-called radiation stresses. These stresses are related to the wave quantities of Delft3D-WAVE by a closure model.

It is assumed that a velocity point is set dry when the actual water depth is bellow half of a user-defined threshold. If the point is set dry, then the velocity at that point is set to zero. The velocity point is set wet again when the local water depth is above the threshold. The hysteresis between drying and flooding is introduced to prevent drying and flooding in two consecutive time steps. The drying and flooding procedure leads to a discontinuous movement of the closed boundaries at tidal effects.

A continuity cell is set dry when the four surrounding velocity points at the grid cell faces are dry or when the actual water depth at the cell centre is bellow zero (negative volume).

The flux of matter through a closed wall and through the bed is zero.

Without specification of a temperature model, the heat exchange through the free surface is zero. The heat loss through the bottom is always zero.

If the total heat flux through the water surface is computed using a temperature excess model the exchange coefficient is a function of temperature and wind speed and is determined according to Sweers (1976). The natural background temperature is assumed constant in space and may vary in time. In the other heat flux formulations the fluxes due to solar radiation, atmospheric and back radiation, convection, and heat loss due to evaporation are modelled separately.

The effect of precipitation on the water temperature is accounted for.

### 3.3.5 Waves

Wave effects can also be included in a DELFT3D-FLOW simulation by running the separate DELFT3D-WAVE module. A call to the DELFT3D-WAVE module must be made prior to running the FLOW module. This will result in a communication file being stored which contains the results of the wave simulation (RMS wave height, peak spectral period, wave direction, mass fluxes, etc.) on the same computational grid as is used by the FLOW module. The FLOW module can then read the wave results and include them in flow calculations.

#### 3.3.5.1 Wave Effects

In coastal seas wave action may influence morphology for a number of reasons. The following processes are presently accounted for in DELFT3D-FLOW.

1. Wave forcing due to breaking (by radiation stress gradients) is modelled as a shear stress at the water surface

2. The effect of the enhanced bed shear stress on the flow simulation is accounted for by following the parameterizations of Soulsby et al. (1993**)**. Of the several models available, the simulations presented in this report use the wave-current interaction model of Fredsoe (1984).

3. The wave-induced mass flux is included and is adjusted for the vertically non uniform Stokes drift.

4. The additional turbulence production due to dissipation in the bottom wave boundary layer and due to wave white capping and breaking at the surface is included as extra production terms in the $k-\varepsilon$ turbulence closure model.

5. Streaming (a wave-induced current in the bottom boundary layer directed in the direction of wave propagation) is modelled as an additional shear stress acting across the thickness of the bottom wave boundary layer.

Processes 3, 4, and 5 have only recently been included in DELFT3D-FLOW and are essential if the (wave-averaged) effect of waves on the flow is to be correctly represented in 3D simulations. This is especially important for the accurate modelling of sediment transport in a near-shore coastal zone.

### 3.3.6 Sediment dynamics and bed level evolution

The bed-load transport contributions are based on a quasi-steady approach, which implies that the bed-load transport is assumed to respond almost instantaneously to orbital velocities within the wave cycle and to the prevailing current-velocity. Similarly, the wave-related suspended load transport contribution is assumed to respond almost instantaneously to the orbital velocities. These transport contributions ($S_{b,c}$ , $S_{b,w}$ and $S_{s,w}$) can be formulated in terms of time-averaged (over the wave period) parameters resulting in relatively simple transport expressions. Where $S_{b,c}$ , $S_{b,w}$ and $S_{s,w}$ are respectively current-related bed load transport ,wave related bed load transport and eave-related suspended transport.

The current-related suspended load transport is based on the variation of the suspended sand concentration field due to the effects of currents and waves. Using a 2DH-approach, the sand concentration field is described in terms of the depth-averaged equilibrium sand concentration derived from equilibrium transport formulations and an adjustment factor based on the (numerical) method of Galappatti.

### 3.3.7 Dimensional advection-diffusion equation for current-related suspended transport

The local flow velocities and eddy diffusivities are based on the results of the hydrodynamic computations. Computationally, the three-dimensional transport of sediment is computed in exactly the same way as the transport of any other conservative constituent, such as salinity, heat, and constituents. There are, however, a number of important differences between sediment and other constituents. For example, the exchange of sediment between the bed and the flow, and the settling velocity of sediment under the action of gravity. These additional processes for sediment are obviously of critical importance. Other processes such as the effect that sediment has on the local mixture density, and hence on turbulence damping, can also be taken into account. In addition, if a

net flux of sediment from the bed to the flow, or vice versa, occurs then the resulting change in the bathymetry should influence subsequent hydrodynamic calculations. The formulation of several of these processes are sediment-type specific, this especially applies for sand and mud.

### 3.3.8 Sediment mixing and dispersion

DELFT3D-FLOW supports four turbulence closure models:

1. Constant coefficient.
2. Algebraic eddy viscosity closure model.
3. $k - L$ turbulence closure model.
3. $k - \varepsilon$ turbulence closure model.

The first is a simple constant value which is specified by the user. A constant eddy viscosity will lead to parabolic vertical velocity profiles (laminar flow). The other three turbulence closure models are based on the eddy viscosity concept of Kolmogorov (1942) and Prandtl (1945**)** and offer zero, first, and second order closures for the turbulent kinetic energy ($k$) and for the mixing length ($L$). All three of the more advanced turbulence closure models take into account the effect that a vertical density gradient has on damping the amount of vertical turbulent mixing.

### 3.3.9 Bed load transport

Bed-load transport is calculated for all “sand” sediment fractions by broadly following the approach described by Van Rijn (1993, 2000). This accounts for the near-bed sediment transport occurring below the reference height $a$ described above.

The approach first computes the magnitude and direction of the bed-load “sand” transport using by Van Rijn. The computed sediment transport vectors are then relocated from water level points to velocity points using an “upwind” computational scheme to ensure numerical stability. Finally the transport components are adjusted for bed-slope effects.

### 3.3.10 Wave-related suspended transport

The wave-related suspended transport is an estimation of the suspended sediment transport due to wave velocity asymmetry effects. This is intended to model the effect of asymmetric wave orbital velocities on the transport of suspended material within about 0.5m of the bed (the bulk of the suspended transport affected by high frequency wave oscillations).

### 3.3.11 Transport formulations for non-cohesive sediment:

Delft3D flow offers different Add-on for standard sediment transport formulations for non-cohesive sediment. Below a list of available formulas are given. Other than these user can also use his own sediment transport formula by making DLL and call it from Delft3D flow.

1. Van Rijn (1993)
2. Engelund-Hansen (1967)
3. Meyer-Peter-Muller (1948)
4. General formula
5. Bijker (1971)
6. Van Rijn (1984)
7. Soulsby/Van Rijn
8 .Soulsby
9. Ashida Michiue (1974)

### 3.3.12 Delft3D Modules

Delft3D simulates the time and space variations of six phenomena and their interconnections in two or three dimensions. The phenomenon are flows, sediment transports, waves, water quality, morphological developments and ecology. To achieve the interaction between different modules, Delft3D consists of several modules, grouped around a mutual interface, which are linked and capable to interact among them. These modules can run independently and generate output. Brief description of the modules are given below

### 3.3.13 Hydrodynamics module (FLOW)

This module basically simulates non-steady flows in relatively shallow water. It takes into account the effects of tides, winds, air pressure, density (due to salinity and temperature) differences, waves, turbulence and drying and flooding of tidal flats. The output of the module is used in all the other modules of Delft3D.

### 3.3.14 Sediment transport module (SED)

In this module sediment transport, erosion and settling of cohesive and non-cohesive, organic or inorganic, suspended or bed sediments are simulated.

### 3.3.15 Morphodynamic module (MOR)

This module computes morphological bottom changes due to sediment transport gradients and user defined, time dependent boundary conditions. Both wind and waves act as driving forces and a number of transport formulae have been built in. An essential feature of this module is the dynamic feedback with the FLOW and WAVE modules, which allow the hydrodynamic flows and waves to adjust them to the local bathymetry and permits for forecasts on any time scale.

### 3.3.16 Delft3D Tools

Other than the modules different pre and post processing tools are used in Delft3D. This includes RGFGRID, QUICKIN, QUICKPLOT which are most frequently used. A brief description of these tools are given below.

### 3.3.17 RGFGRID

RGFGRID is used for generation of both curvilinear and rectangular grid.This allows to generate Orthogonal, curvilinear grids of variable grid sizes for the purpose of computation. It also allows high resolution near the area of interest and relatively low resolution at the model boundaries. Grids may be aligned with the land boundaries smoothly to avoid sharp change in boundary which may cause artificial diffusion. Various grid manipulation options are provided in order tune the grid as well as control the grid generation process.

### 3.3.18 QUICKIN

This program is used for interpolation and generation of bathymetry. Usually raw data are obtained as points which requires further interpolation or averaging to generate a bathymetry for the simulation purpose. This tool also allows to check the courant number for different time steps. Reasonable value of courant number is very much important for the stability of the model.

### 3.3.19 QUICKPLOT

QUICKPLOT is a post-processing program used to visualize the outcome of different simulation processes, with the possibility of a graphical and/or numerical representation of the results. QUICKPLOT allows uniform access to all types of data files produced by the Delft3D modules, to select and visualize computational results and measured data.

## 3.4 Methodology

The major portion of this research work is accomplished with Delft3D. But before that it required to pre-process the data. For the Bay of Bengal along the Cox’s Bazar bathymetry data (latitude, longitude and elevation) of about 86 km sea at 600 m interval was collected from marine drive project. But in Delft3D, sample file can be read only as “xyz file”. So from the bathymetry data (latitude, longitude and elevation) “xyz file” has been prepared and using this Delft3D model was setup. At the beginning curvilinear grid has been created with Delft3D-RGFGRIED, and then the grid was brought to Delft3D-QUICKIN to generate the bathymetry by interpolating from the observed data which was collected from marine drive project. After completing pre-processing these was brought to Delft3D-WAVE for simulation. A file consisting of varying roughness values for the whole grid was imported which was used for calibrating the model. Model was run for several times until it was calibrated with the observed data. After calibration and validation the model was ready to run for morphology under different scenarios.

### 3.4.1 Data Collection and Processing

To assess the hydrodynamic process along the coast of Cox's Bazar, necessary bathymetric data has been collected from Institute of Water Modeling (IWM), Bangladesh Water

Development Board (BWDB) and Bangladesh Metrological Department (BMD) to set up the model. The data has been collected as Longitude, Latitude as unit in degree and Depth in metre for setting up the bathymetry of the study area (Cox's Bazar). These data has been converted from latitude-longitude to UTM (Universal Transverse Mercator) co-ordinate system.

### 3.4.2 Bathymetry from collected data for set up Model

By observing the data of the study area it is found that there are 145 point e. g 145 grid point in along X direction and 40 grid point in along Y direction. By plotting the latitude-longitude co-ordinate in Google earth, we have been located our region of the study area that has been shown in figure 4.1. Figure 4.1 presents the study area which is about 86400 x23400 meter. In this map we can see that the model area consists of a two-way using a mesh of 144 x 39 grid squares with a constant grid spacing of 600 m (meter). The model has three open boundaries: The northern boundary is the Fasiakhali and the southern boundary is in the near Chowdhury Para and the western Boundary is in the open sea located bay of Bengal.

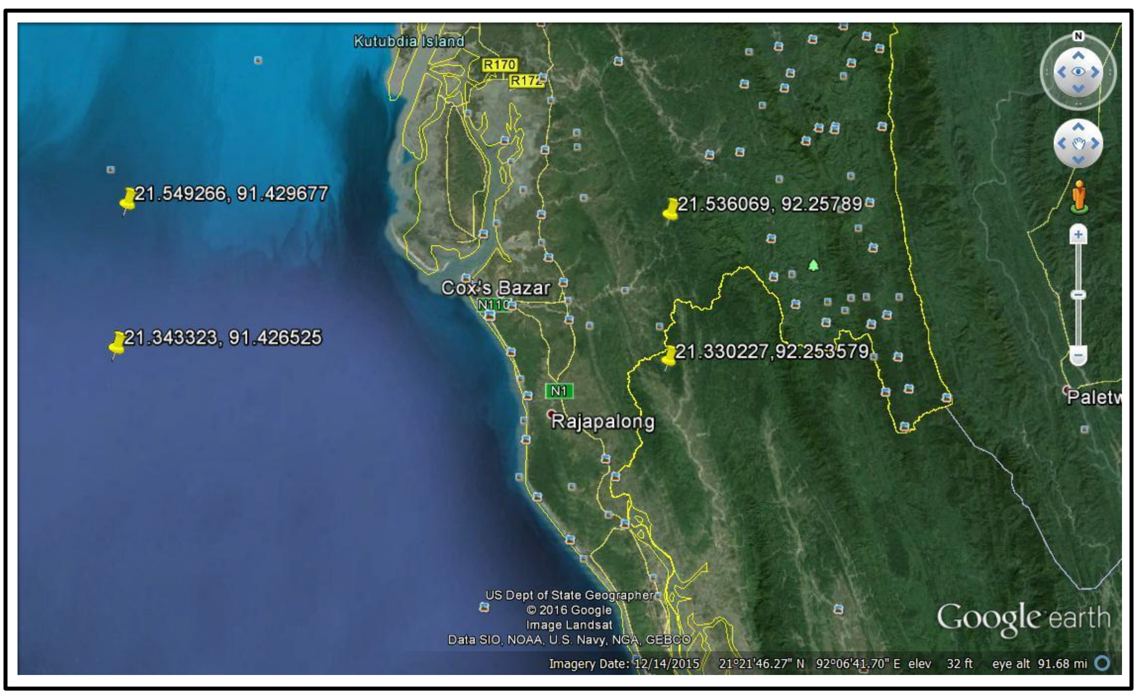


Figure 3.2 Satellite image (Source: Google Earth)

At first latitude longitude data has been rearranged in excel sheet in two columns such that latitude & longitude of a point are in the same row. In this way latitude and longitude of 5616 points of the study area have been arranged. By using the software "LOTE" latitude longitude of the points are converted to UTM co-ordinate system that mean X and Y co-ordinates of the 5616 points are obtained. The output file is saved as text file which can be opened in excel. Again in that output file in excel elevations are rearranged such that corresponding X, Y and Z co-ordinates of each point are in the same row. In the collected elevation data, the data above the MSL (mean sea level) is denoted as positive value and the data below the MSL is denoted as negative value which is oppositely read in Delft3D. In Delft3D the data above MSL or land data is considered negative. So the column of all the elevation data is multiplied by -1. The file is then saved as text file. To make the required xyz file the extension is renamed from .txt to .xyz file which can be opened in Delft3D as sample file.

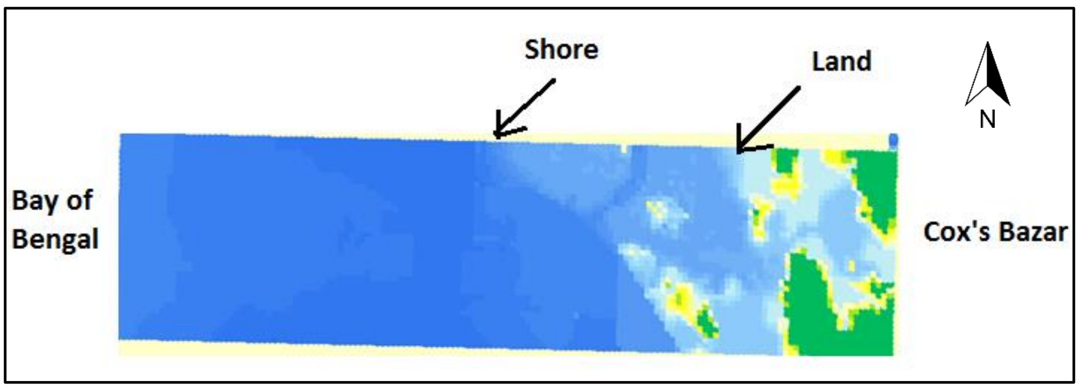


Figure 3.2: Bathymetry of Bay of Bengal in Delft Quickin

### 3.4.3 Grid generation

Delft3D-Wave requires two dimensional curvilinear grid for flow simulation. Different tools are available there for generating this grid. In this research RGFGRID is used which is a utility of Delft3D. RGFGRID is capable of generating grid in both Cartesian and Spherical co-ordinate. At first spline was made covering the Bay of Bengal along Cox's Bazar coast, this spline was converted to grid. The grid was refined and finally 250 by 70 grids were taken. Local refinement was done near coastline in order to better approximate the results of imposed scenario at this location.

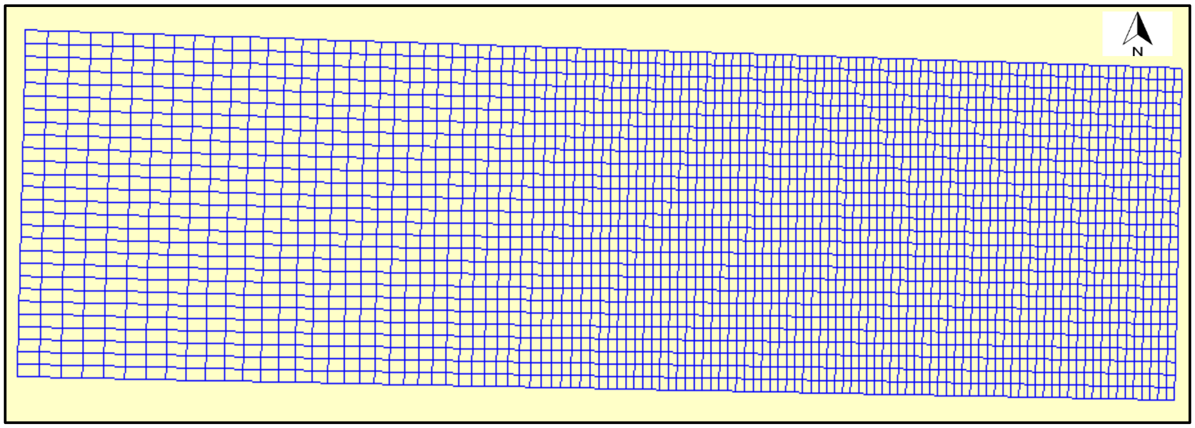


Figure 3.3: grid

This grid was further exported for bathymetry generation.

### 3.4.4 Orthogonalise

After grid generation it is necessary to orthogonalize (rectangular pattern) this grid to meet the Delft3D computational requirement of orthogonality. It is the cosine value of grid corners. For better approximation this values should be as close to zero as possible. The error in the computed direction is proportional to this value. In the present model orthogonality was found below 0.02 in almost all cells except a slight portion where it is about 0.09. It can be considered acceptable for the study.

### 3.4.5 Generated Bathymetry

QUICKIN was used to assign the collected bathymetric data to the grid points and generate a bathymetry for the simulation. It followed a series of operation, which are grid cell averaging, triangular interpolation and internal diffusion. After interpolation the bathymetry was smoothened to avoid unrealistic sharp change in cross section. Using polygon in Delft3D it is possible to smoothen different portion locally which makes the work quite easy.

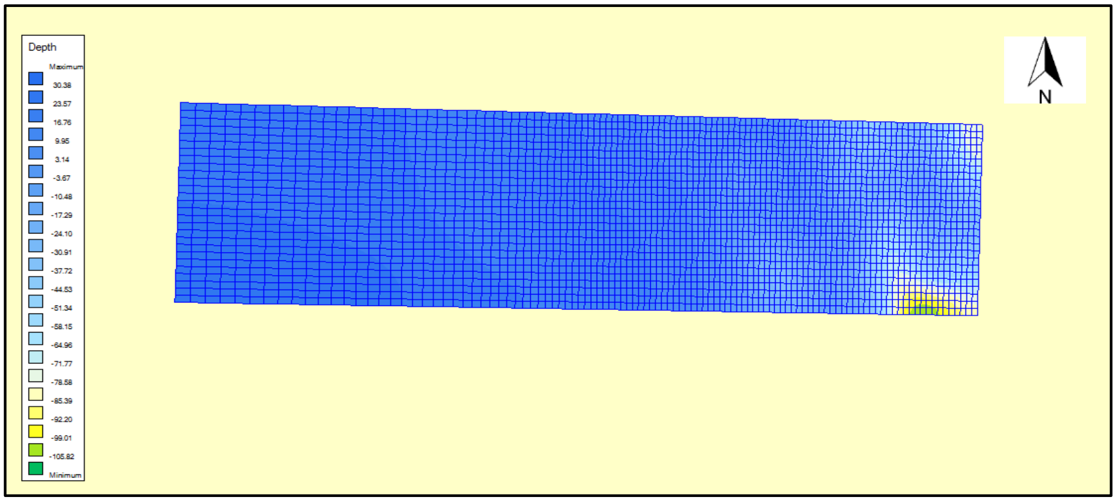

Figure 3.4: Generated Bathymetry

### 3.4.6 DELFT3D FLOW Setup

The model has been setup using Flow module through GUI. At first the grid fil and depth file (Bathymetry) were located. It requires the location of the project area to calculate the Coriolis effect if spherical coordinate is used, in the present model Cartesian coordinate has been used where the Coriolis effect is not taken under consideration. Several steps involved in setting up the model are described below.

### 3.4.7 Courant number

Courant number is important for the stability of the model. De1ft3D QUICKIN has an option to check the Courant number for a given depth file. This model has been checked for different time steps such as 15,10,20,30 minute time steps. For better approximation 1 min time step has been taken in this m Courant number is below 1 model where the maximum at almost all portion of the area. Generally, the Courant number should not exceed a value of ten, but with problem with rather small variation in both space and time the Courant number can be taken larger. (WL, Delft Hydraulics, 2005a)

### 3.4.8 Initial and Boundary Conditions

Initial condition Initial condition is the hydrodynamic condition at the beginning of the simulation, it is another pre-requisite of any model. For upstream and downstream end

initial condition can be easily known from the boundary conditions, but for all other grid points initial condition is not available at the beginning. One way is cold start, initial downstream water surface elevation must be provided in such a manner that all the mesh nodes of the model remain submerged, otherwise the steady solution may diverge. For simplicity, the initial water level for the whole domain was assumed same as the downstream water level.

### 3.4.9 Hydrodynamic Parameters

For hydrodynamic simulation some parameters are to be defined, it includes rough-ness parameter (Manning's n), horizontal eddy viscosity, horizontal eddy diffusivity. Roughness value is important as the velocity of flow greatly depends on it. Manning's n is used for hydrodynamic calibration; this model is run for varying roughness values and calibrated with the observed water level.

**Table 3.1:** Hydrodynamic parameters

| Hydrodynamic parameters | Value |
|---|---|
| Gravity | 9.81 m/s$^2$ |
| Water density | 1000 kg/m$^3$ |
| Roughness | n=0.022-0.029 |
| Horizontal eddy viscosity | 1 m$^2$/s |

### 3.4.10 Unsteady flow simulation

After adjusting different physical numerical parameters through Flow-GUI the model was ready for unsteady flow simulation. Physical parameters are hydrodynamic constants, bottom roughness, and viscosity. For bed roughness one can enter uniform value of space varying values. For this model space varying roughness value Manning's n was used. It requires initial and boundary conditions which have been described earlier. Time step used is one minute and the simulation time spanned between 17 February and 23 February 2016.

### 3.4.11 Morphological Parameter:

Morphological module is used to simulate the morphological changes of the river. The hydrodynamic output of the FLOW module is used by DELFT3D-MOR to generate

outputs. Various inputs associated with this module are sediment transport predictor, grain size etc. The model requires certain physical parameters to be ascertained for sediment transport and morphological change. These includes specific density, dry bed density, sediment diameter (d50), spin up interval, minimum depth for sediment calculation, van Rijn's reference height factor, threshold sediment thickness, morphological scale factor. All the values are shown in tabular format.

### 3.4.12 DELFT3D Wave Setup

For morphological analysis due to wave action both wave and flow has to be run using the same grid, depth file. Other parameters are almost same and boundary condition is provided in north, south and west direction at angles 220° and 240° with respect to north

After simulation of both flow and wave outputs are observed in quickplot.

## 3.5 Model Calibration

Model calibration is iterative process which involves adjusting certain parameters to obtain certain level of accuracy. Experience and good understanding of hydraulics important in selecting these parameters. For simplicity usually few parameters are dealt first, after that others are adjusted. There may exist number of uncertainties, such as boundary condition, geometry etc. After adjusting these basic information to obtain reasonable accuracy the model is further proceed for calibration process.

### 3.5.1 Calibration by Observing Significant Wave height

Firstly calibration is proceeded by comparing the measured and simulated significant wave height. For Calibration simulation is run for 5 days from January 9 2013.By adjusting coefficients of friction parameter an approximate close result is found. The result is shown in the figure below

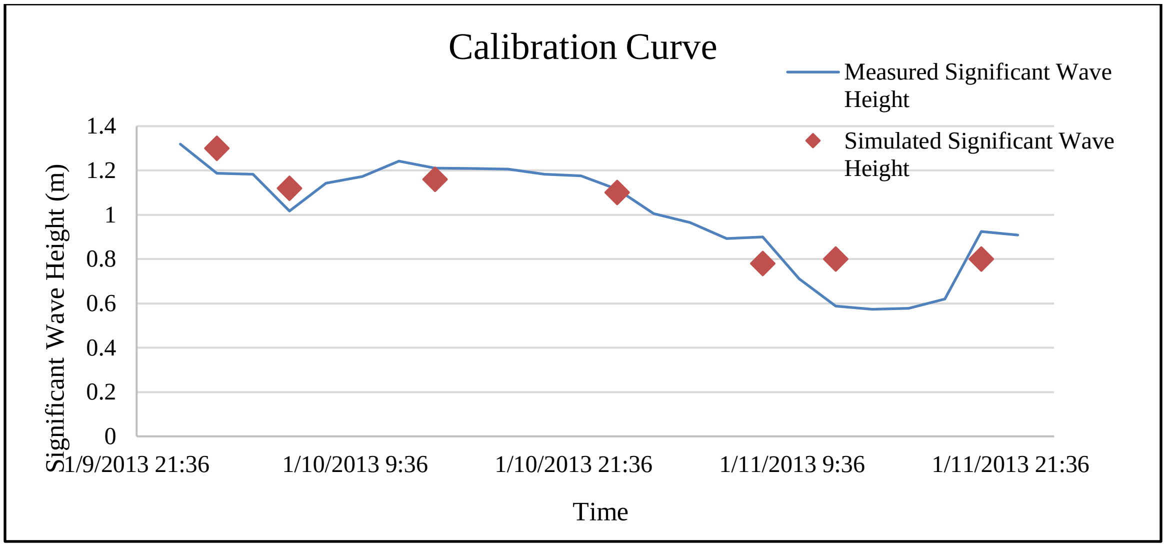


Figure 3.5: Calibration by observing significant wave height

# Chapter 4

# Results and Discussions

## 4.1 General

Deft3D model has been used for wave, hydrodynamic and morphological modeling in this research as described earlier. Initially surveyed bathymetric data of the Bay of Bengal at Cox’s bazar has been used here for simulation. From the bathymetry it is clear that the sea follows a very mild slope in strip portion of the study area. The wave height, velocity profile and morphology also change with bathymetry. Change in different hydrodynamic and morphological characteristics have been analyzed. Different cross sections throughout the area were taken for assessing different characteristics. Model results after applying used to determine the sediment load at different section of the sea.

## 4.2 Study Area

Wave in Bangladesh coast originates in India Ocean. It enters the Bay of Bengal through the two submarine canyons, the ' Swatch of No Ground' and the 'Burma Trench' and thus arrives very near to the 10 fathom contour line at Hiron Point and Cox's Bazar respectively. Wave in Bangladesh coast originates in India Ocean. It enters the Bay of Bengal through the two submarine canyons, the 'Swatch of No Ground' and the 'Burma Trench' and thus arrives very near to the 10 fathom contour line at Hiron Point and Cox's Bazar respectively. The study area which has been located in the Bay of Bengal near the Cox’s Bazar. The study area has been set up based on data of Cox's bazar from Maheshkhali channel to Inani Sea beach of Bay of Bengal. In Figure 4.1 has been shown the study area. A wave has been travelling from deep water to shallow water due to gradients (spatial differences in surface level) in the water surface. As water always flows to the lowest point, these gradients are the cause of wave or tidal flows. Just like tidal wave, this flow is periodical and changes from flood when the flow is directed upstream towards land to ebb when the flow is directed back towards the sea.

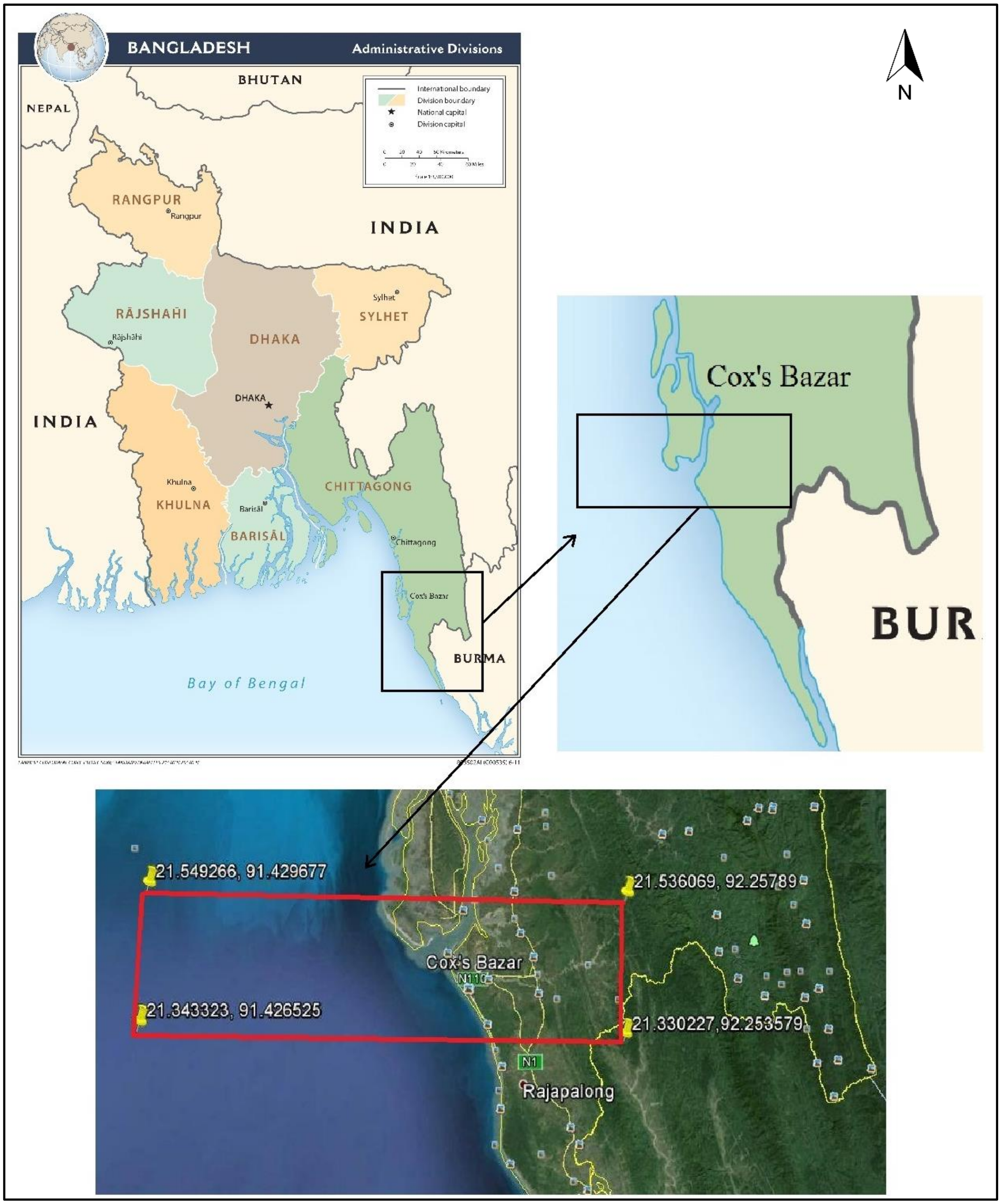


Figure 4.1: Study Area

## 4.3 Variation in Sediment Transport

Sediment transport characteristics is influenced by the tidal effect. A series of figures describes the variation of sediment transport all through the model. It is clear that sediment transport rate is at deep sea compared to nearshore. Such variation is mainly due to the higer wave force.

In all conditions the relative magnitude of sediment transport is almost the same. Some portion from the deep sea is having higher transport rate. This causes higher erosion/deposition in this portion. Very small portion near deep sea is also having relatively high sediment transport, this occurs due to the presence of underwater dune shape configuration which is eroding in nature.

### 4.3.1 Erosion and Deposition Process

Cumulative erosion/deposition throughout the study are is calculated using the model Delft3D for 7 days simulation at wave angle 220° and 240°. A series of figures showing cumulative erosion/ deposition at the end of each day is shown. It is evident that change in river bathymetry is not much for 7 days period and it shows similar type of change at any location.

From the result it can been seen that erosion takes place at some places in deep sea where bed is having relatively higher elevation with respect to the side areas, this undergoes continuous erosion.

Erosion/Deposition for wave angle 220° is shown in the following figure

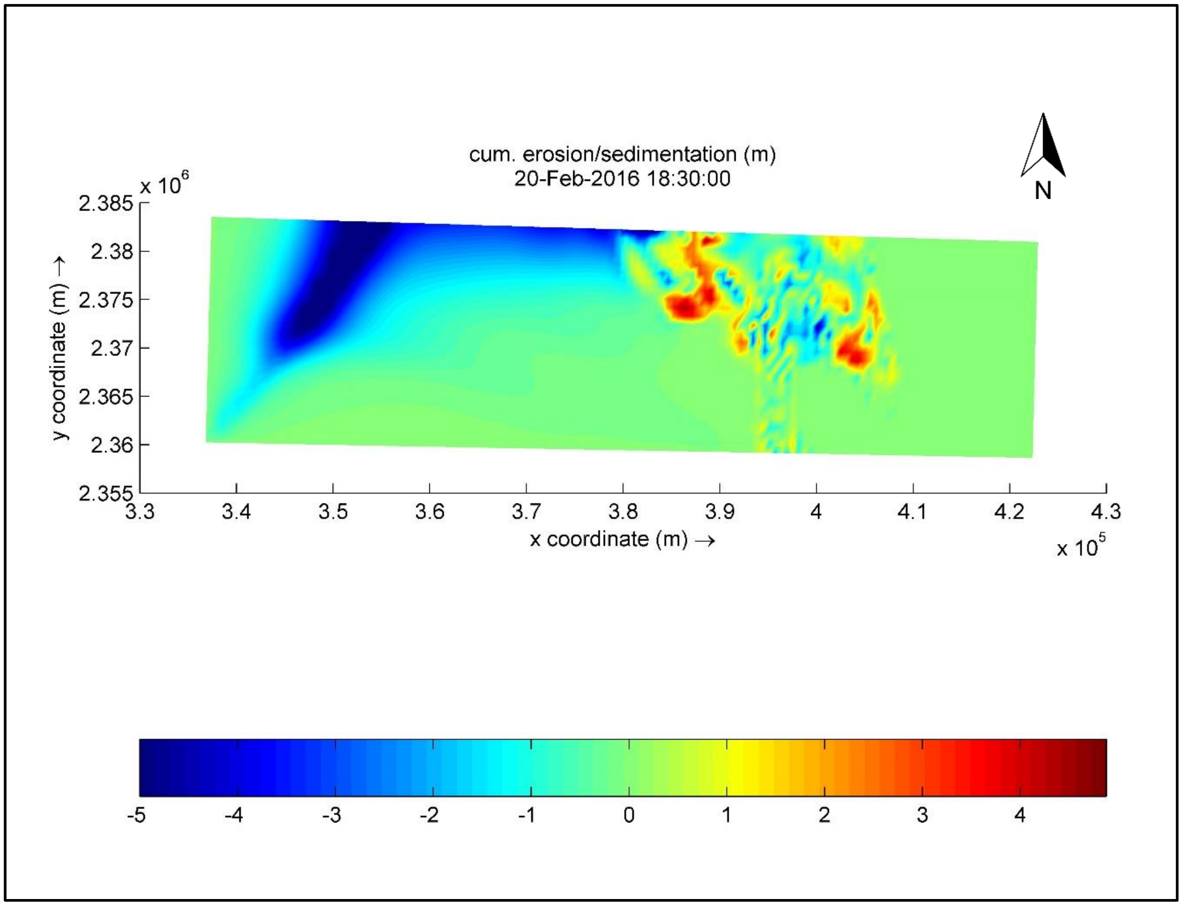


Figure 4.2: Cumulative Erosion/Deposition for wave angle 220°

(Negative Values represents Erosion

and Positive Values represents Deposition )

Erosion/Deposition for wave angle 240° is shown in the following figure

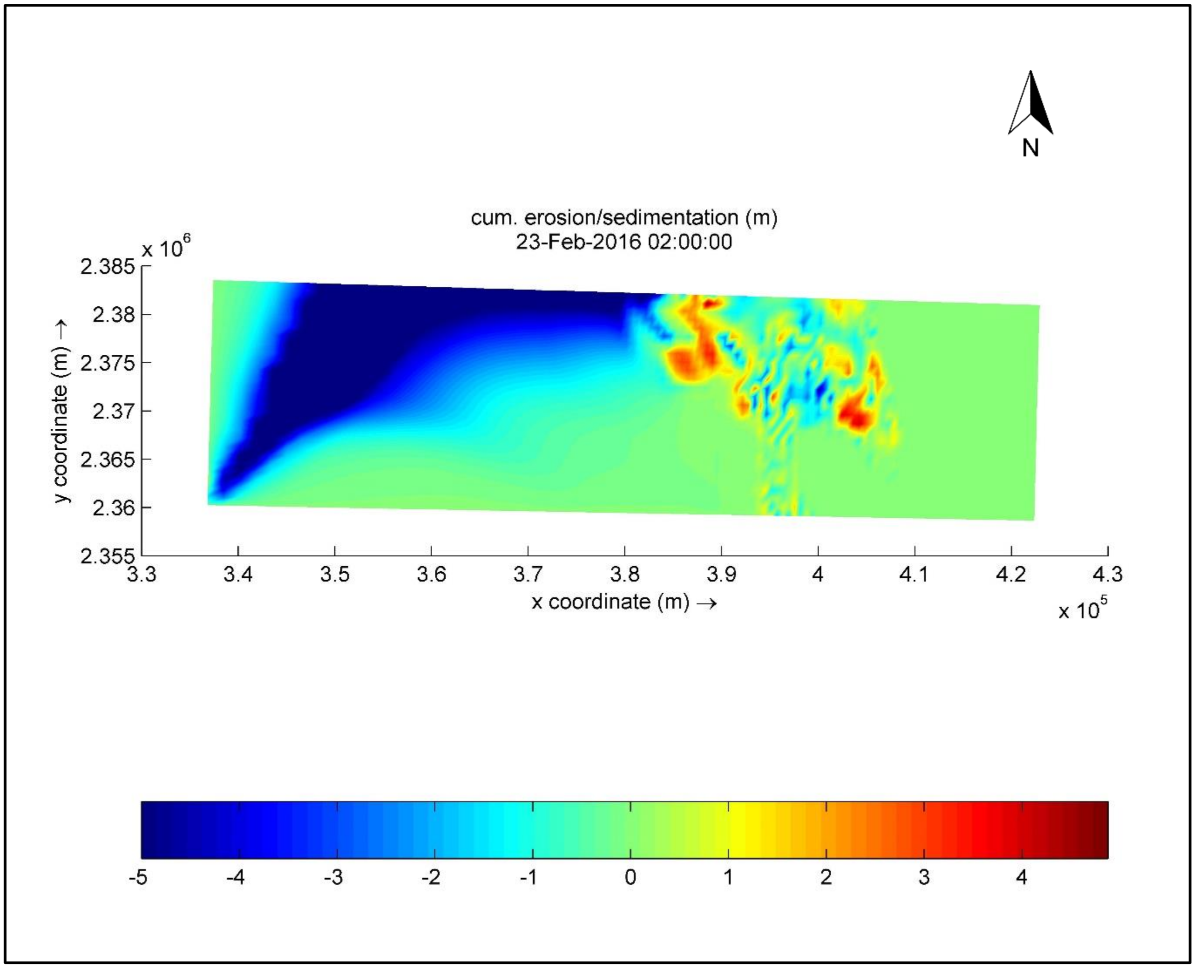


Figure 4.3: Cumulative Erosion/Deposition for wave angle 240°

(Negative Values represents Erosion

and Positive Values represents Deposition )

Erosion/Deposition at different sections for wave angle 220° and 240° along “n” direction are shown in the following figures

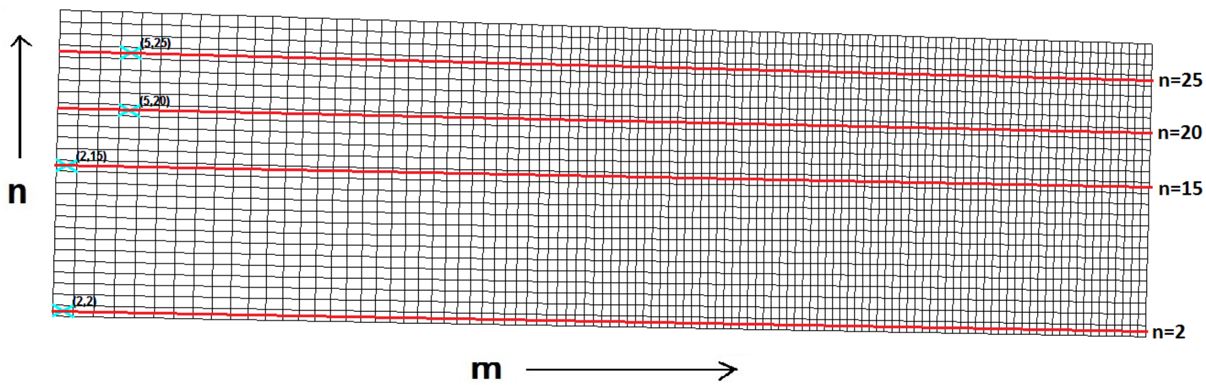


Figure 4.4 Sections along “n” direction taken for observing Erosion/Deposition

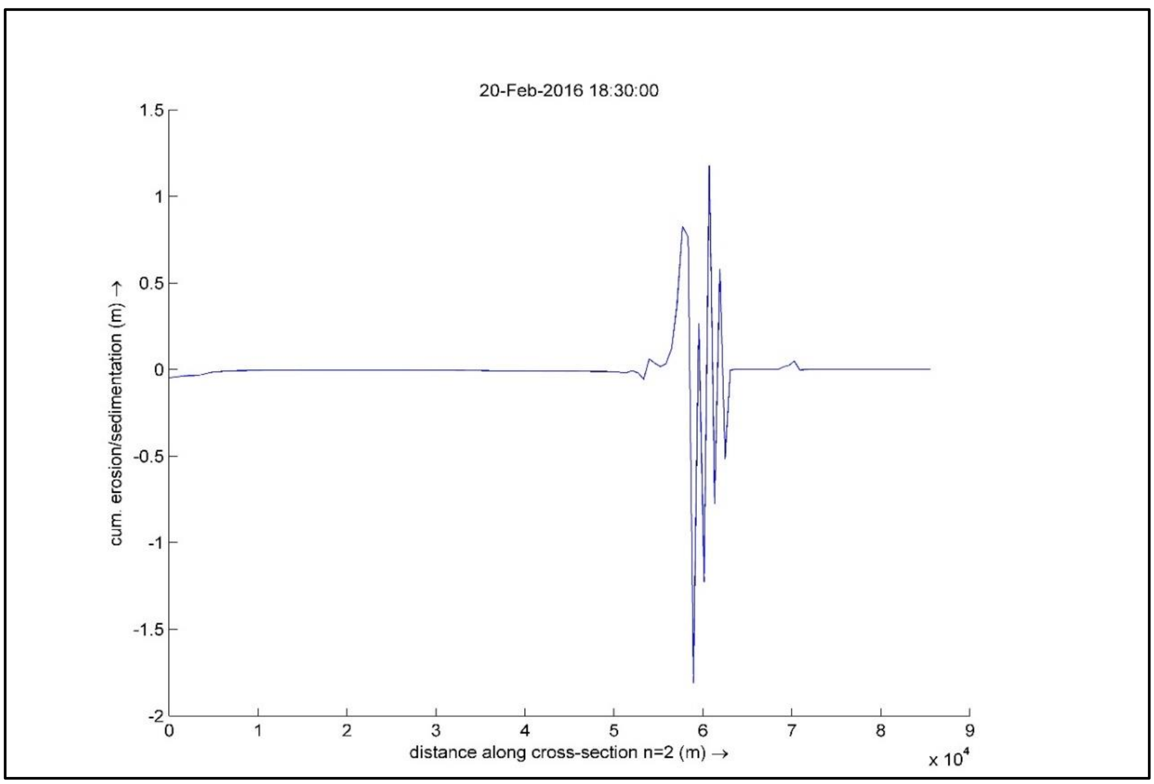


Figure 4.5 Cumulative Erosion/ Deposition at n=2 for wave angle 220°

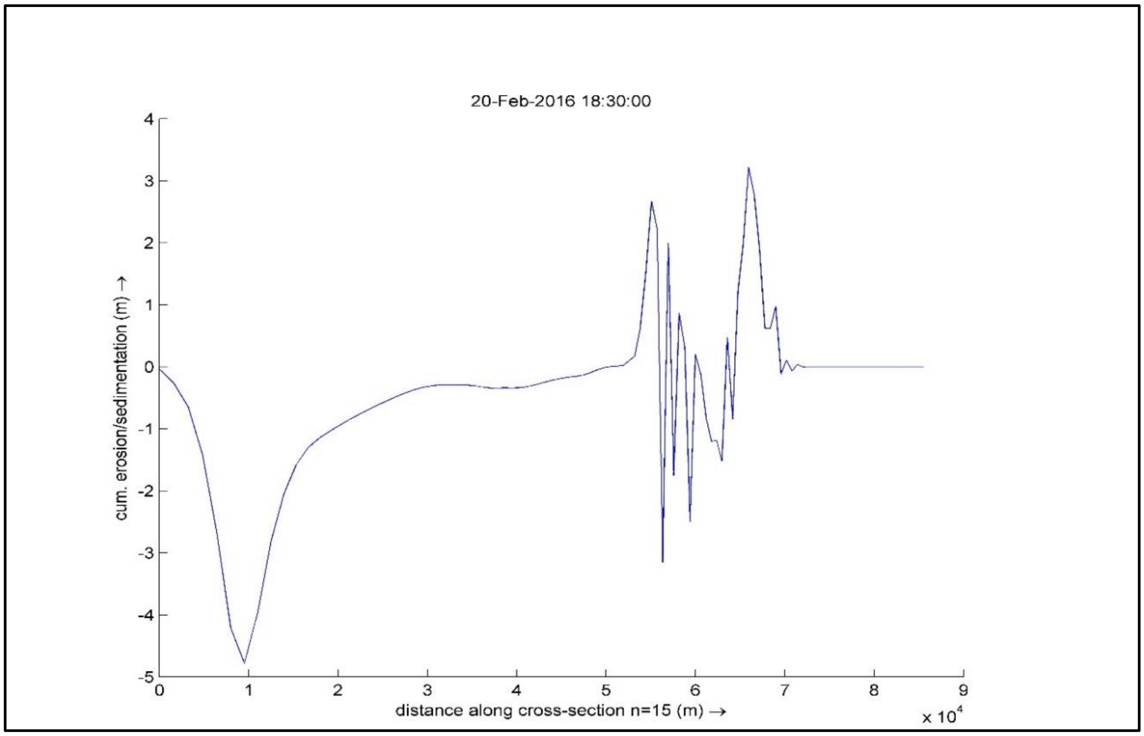


Figure 4.6 Cumulative Erosion/Deposition at n=15 for wave angle 220°

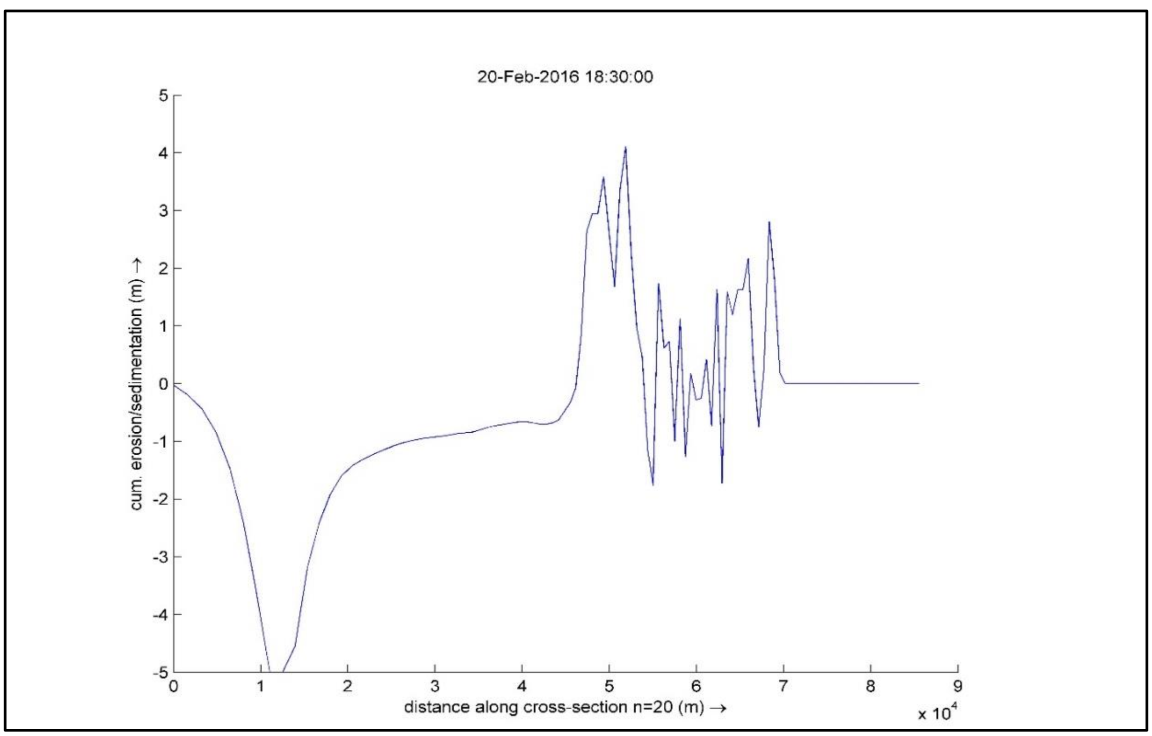


Figure 4.7 Cumulative Erosion/deposition at n=20 for wave angle 220°

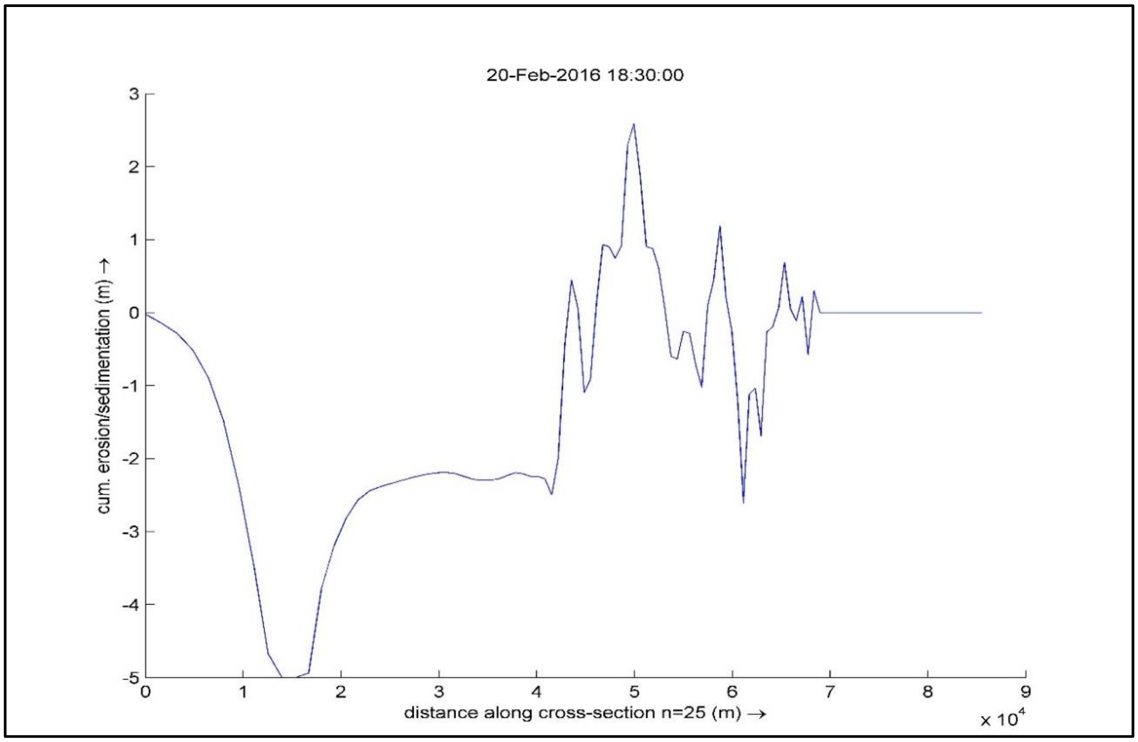


Figure 4.8 Cumulative Erosion/deposition at n=25 for wave angle 220°

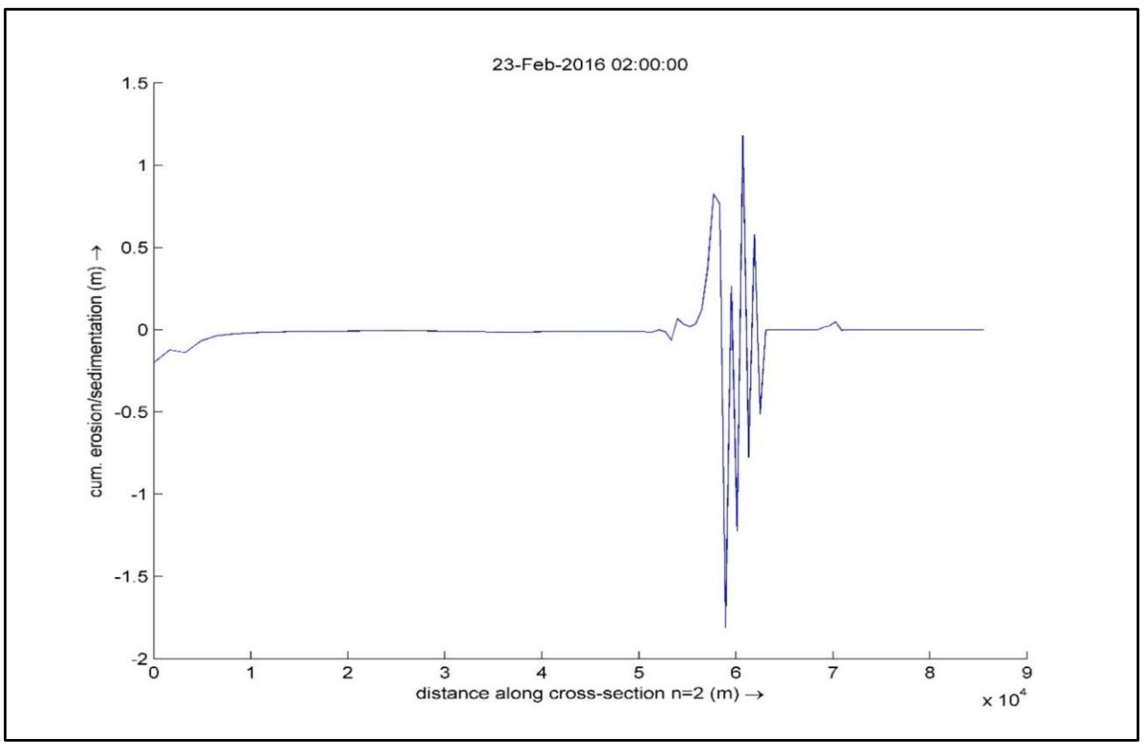


Figure 4.9 Cumulative Erosion/Deposition at n=2 for wave angle 240°

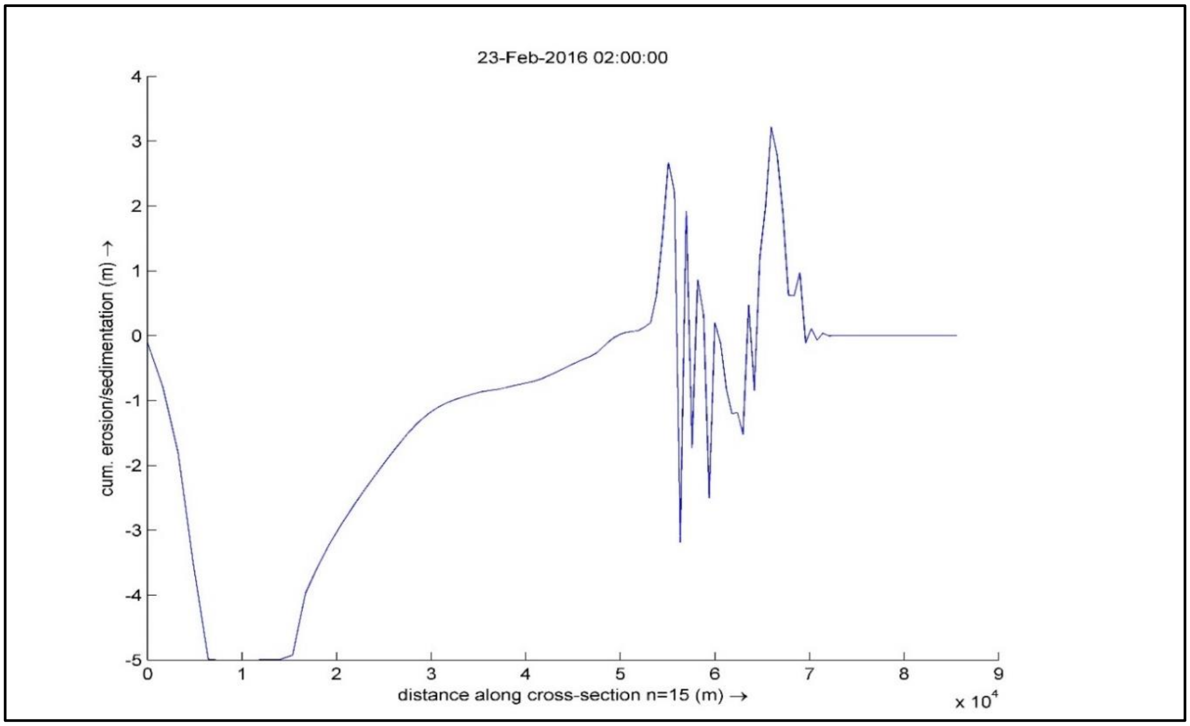


Figure 4.10 Cumulative Erosion/Deposition at n=15 for wave angle 240°

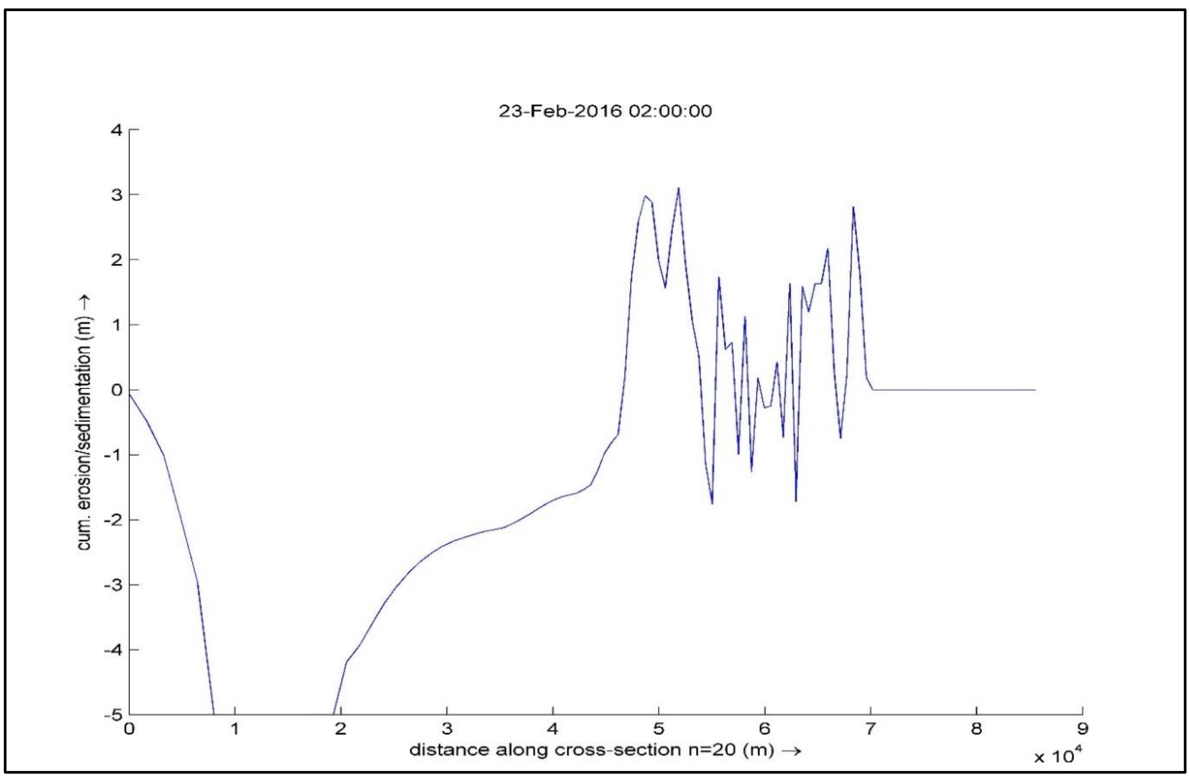


Figure 4.11 Cumulative Erosion/Deposition at n=20 for wave angle 240°

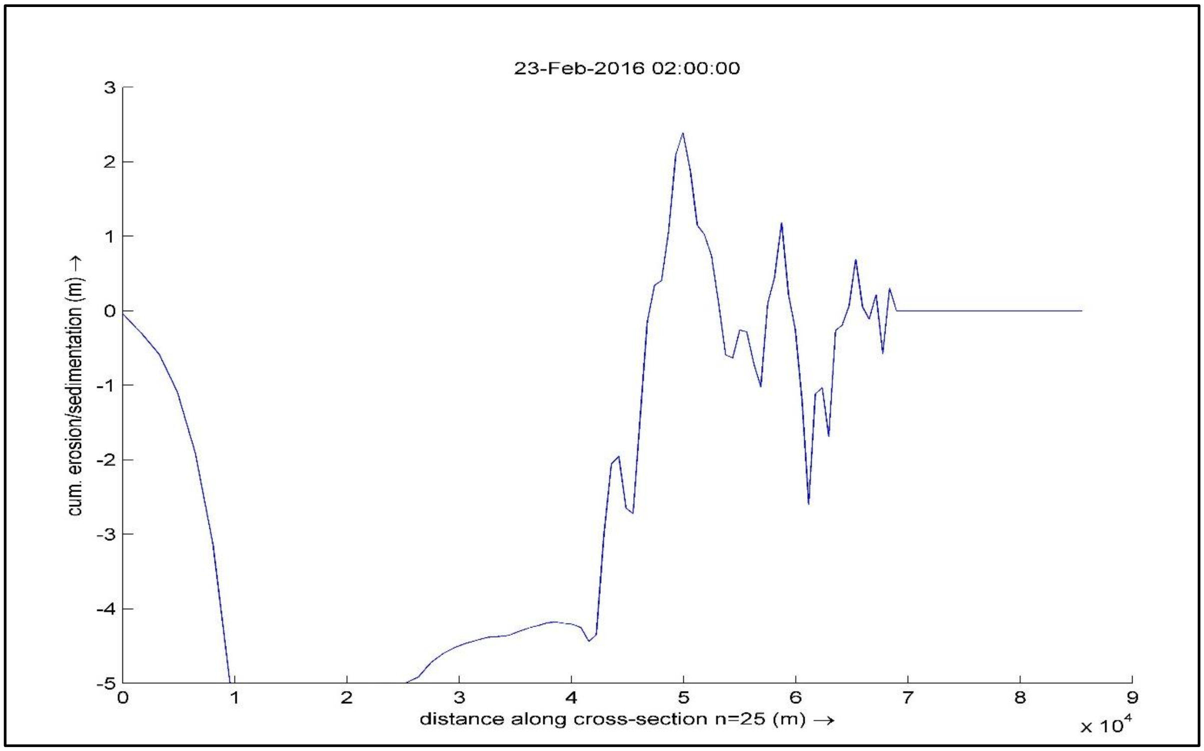


Figure 4.12 Cumulative Erosion/Deposition at n=25 for wave angle 240°

### 4.3.2 Bed Shear Stress Variation

Bed Shear Stress is an important parameter for observing the morphological change due to hydrodynamic process. Erosion occurs in place of higher shear stress. At different sections variation of bed shear stress is by the following figures

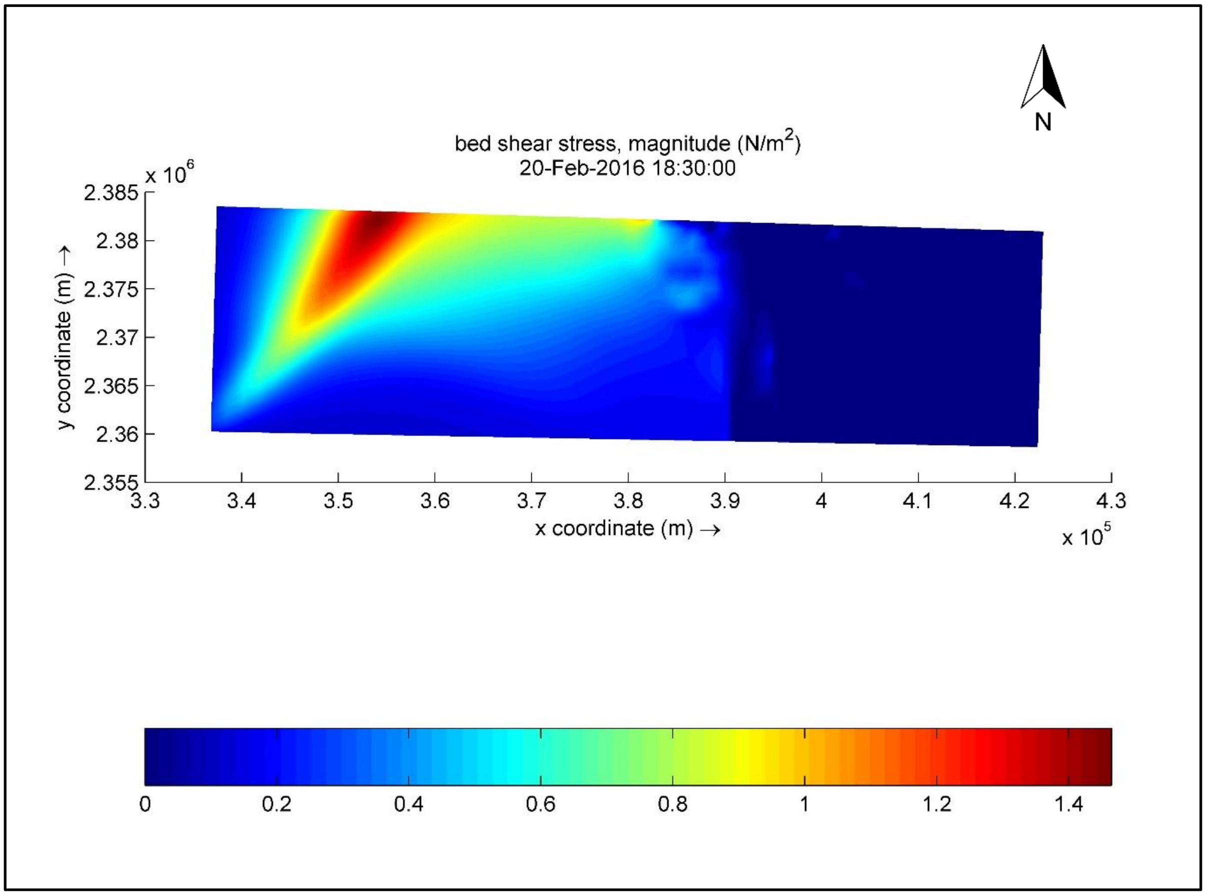


Figure 4.13 Bed shear stress for wave angle 220°

For wave angle 240° variation in bed shear stress is shown in the following figure

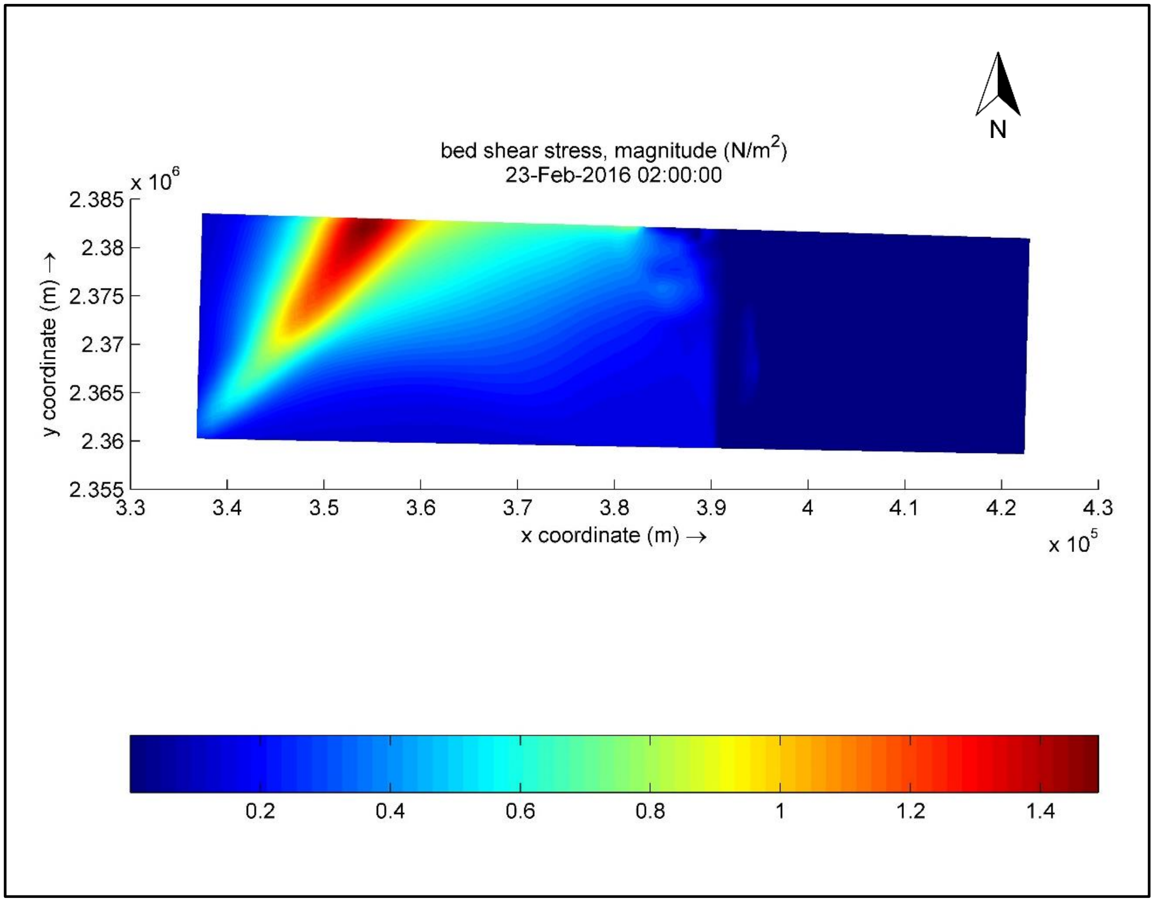


Figure 4.14 Bed shear stress for wave angle 240°

Variation in bed shear stress for wave angle 220° and 240° are shown in the following figures

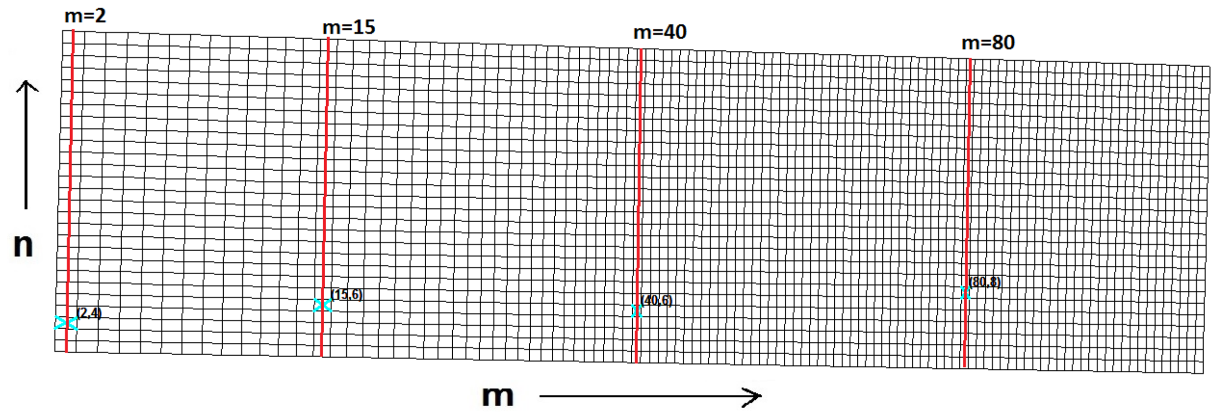


Figure 4.15 Sections along "m" direction taken for observing bed shear stress

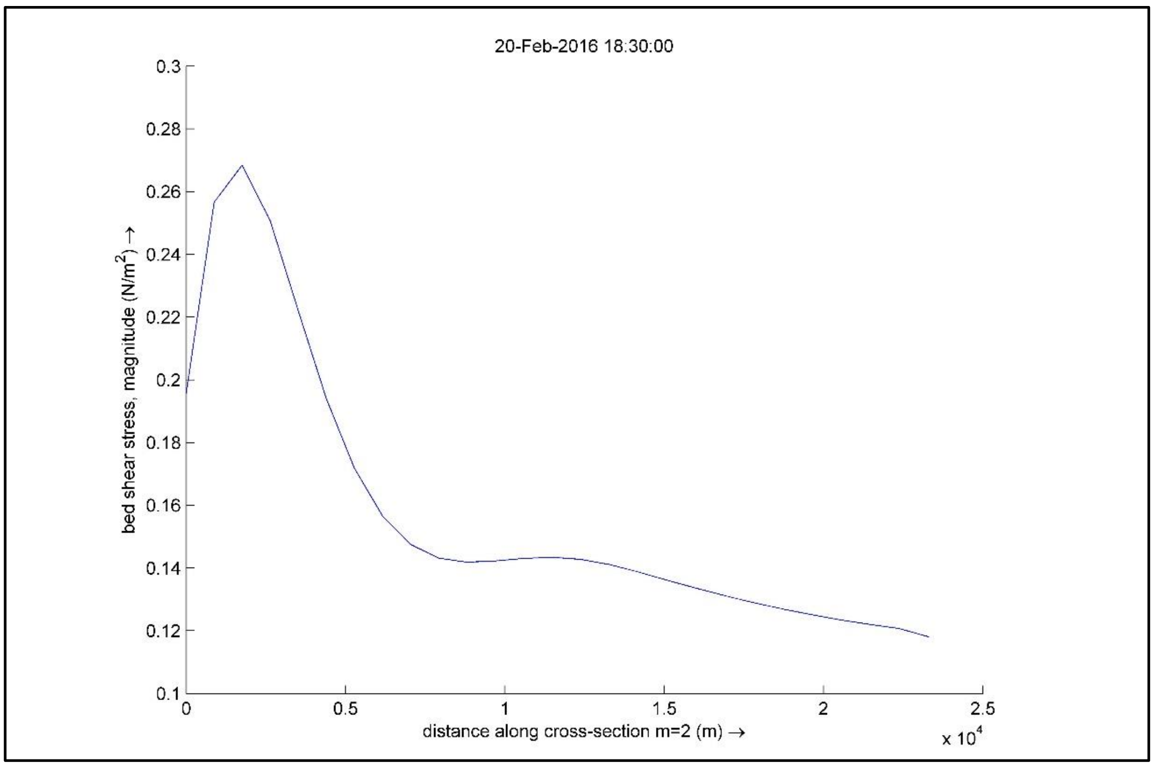


Figure 4.16 Bed shear stress at m=2 for wave angle 220°

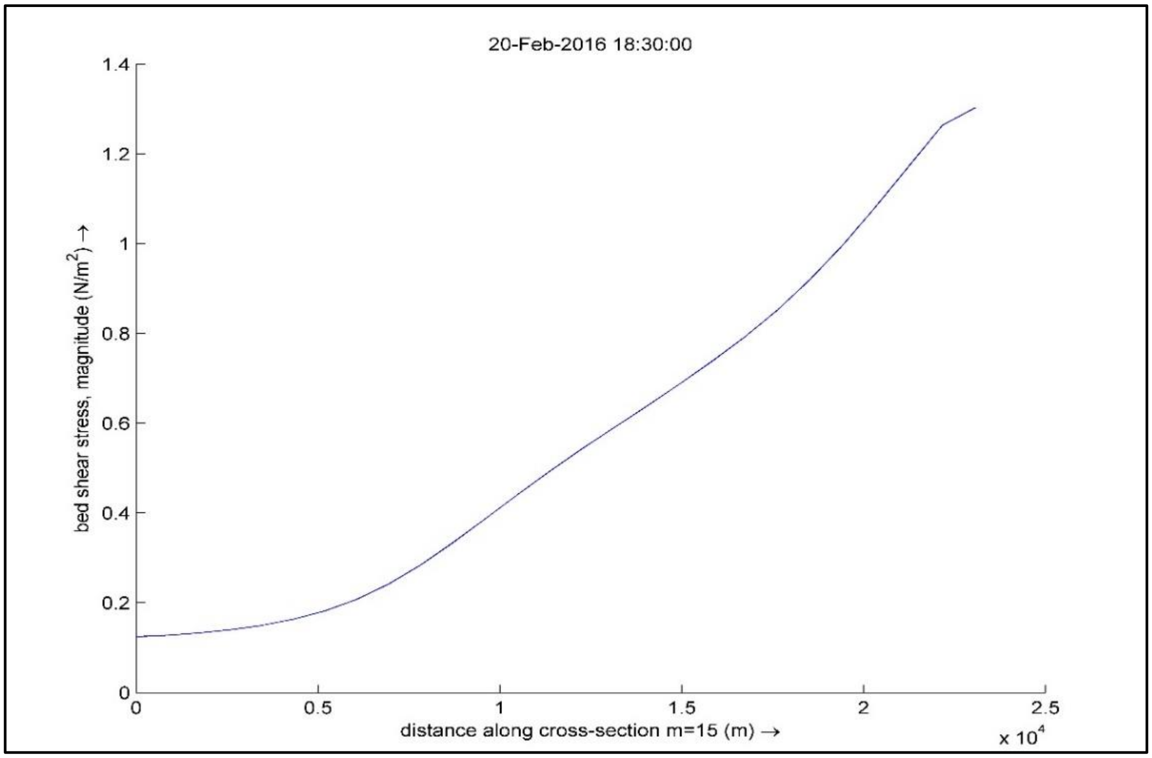


Figure 4.17 Bed shear stress at m=15 for wave angle 220°

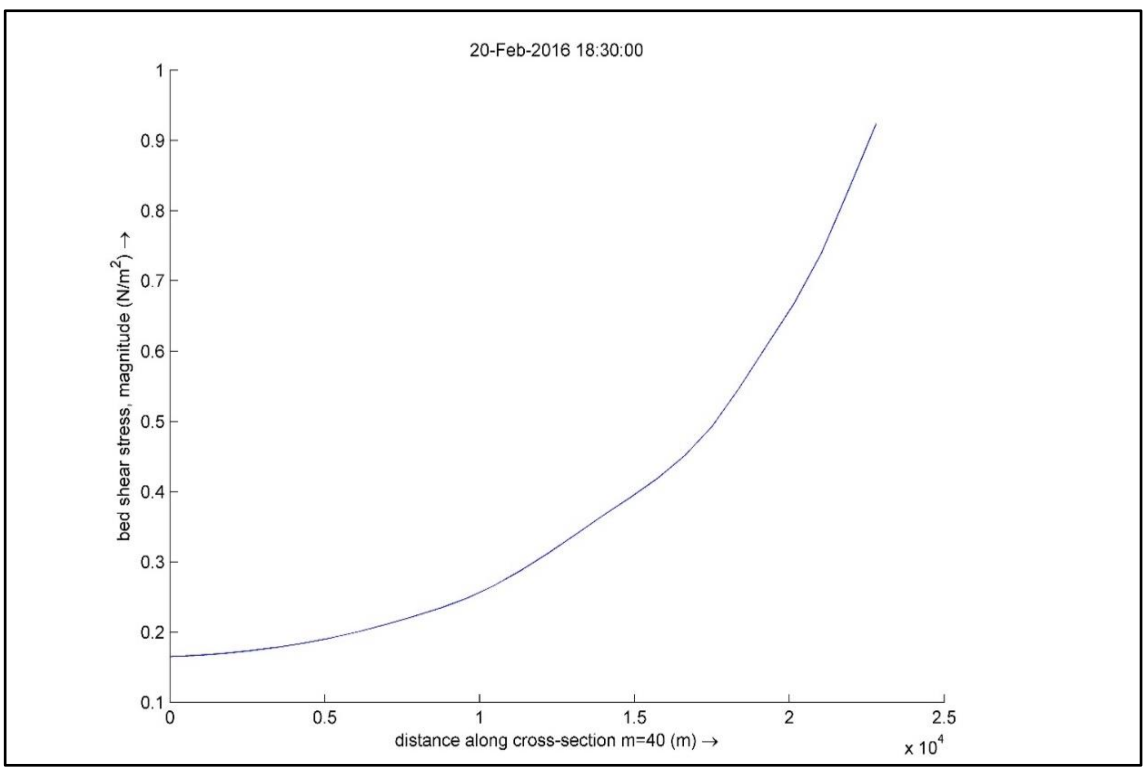


Figure 4.18 Bed shear stress at m=40 for wave angle 220°

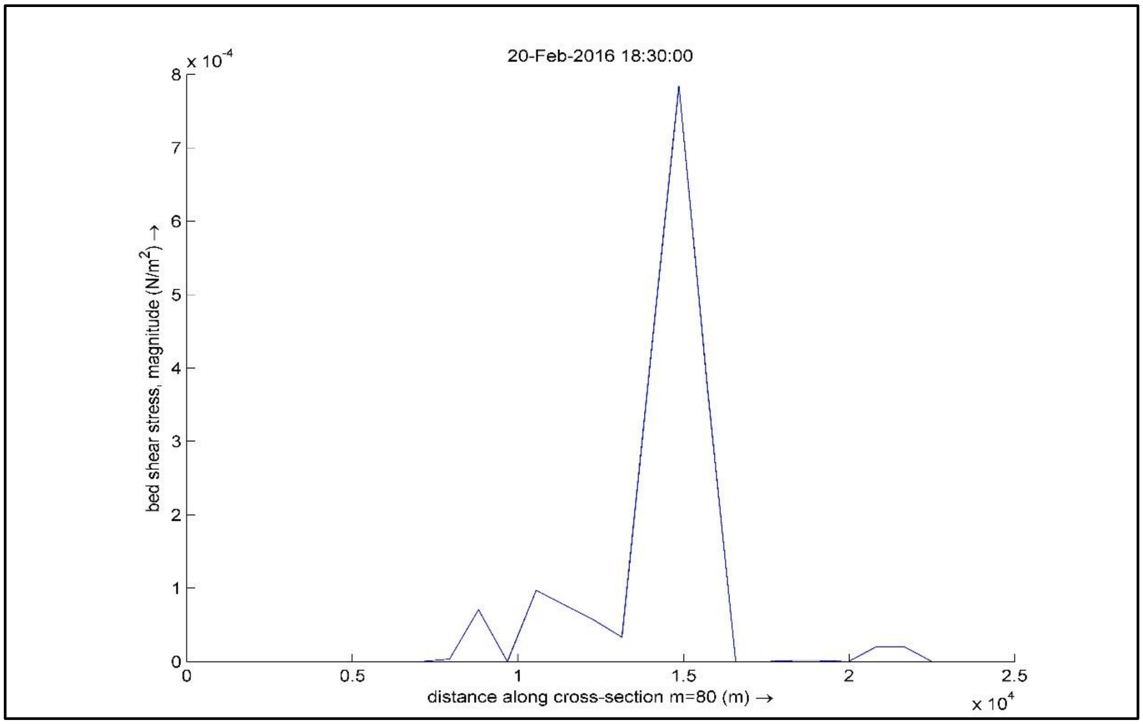


Figure 4.19 Bed shear stress at m=80 for wave angle 220°

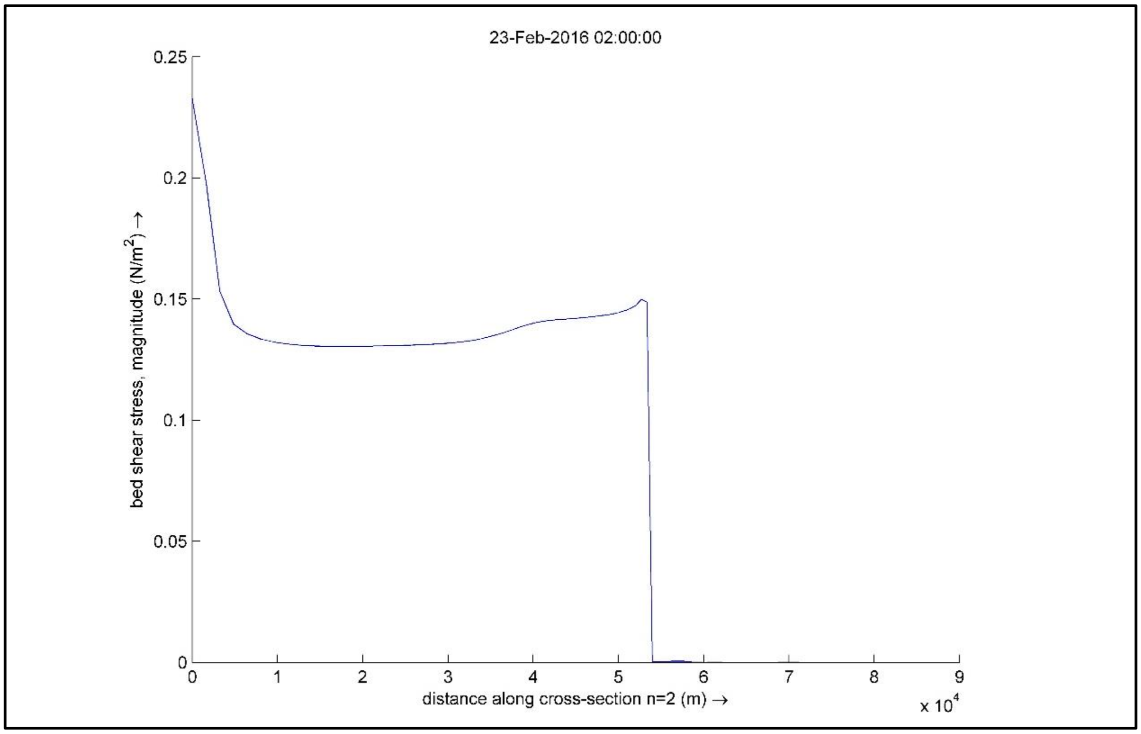


Figure 4.20 Bed shear stress at m=2 for wave angle 240°

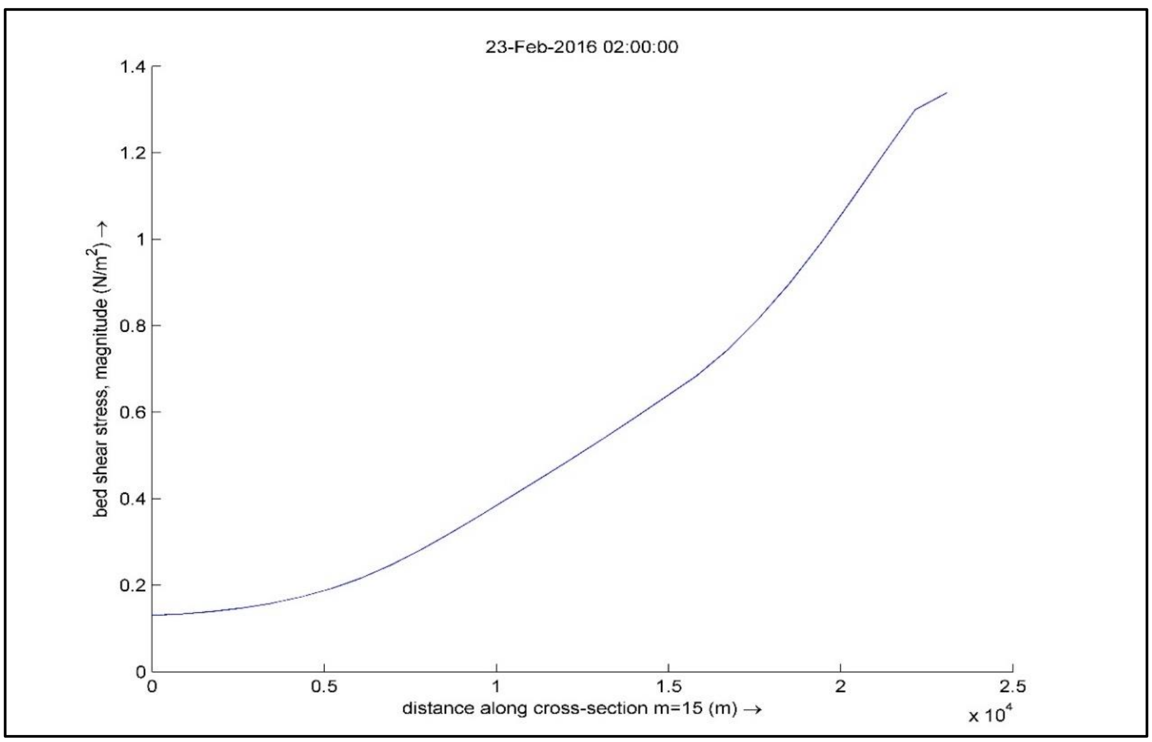


Figure 4.21 Bed shear stress at m=15 for wave angle 240°

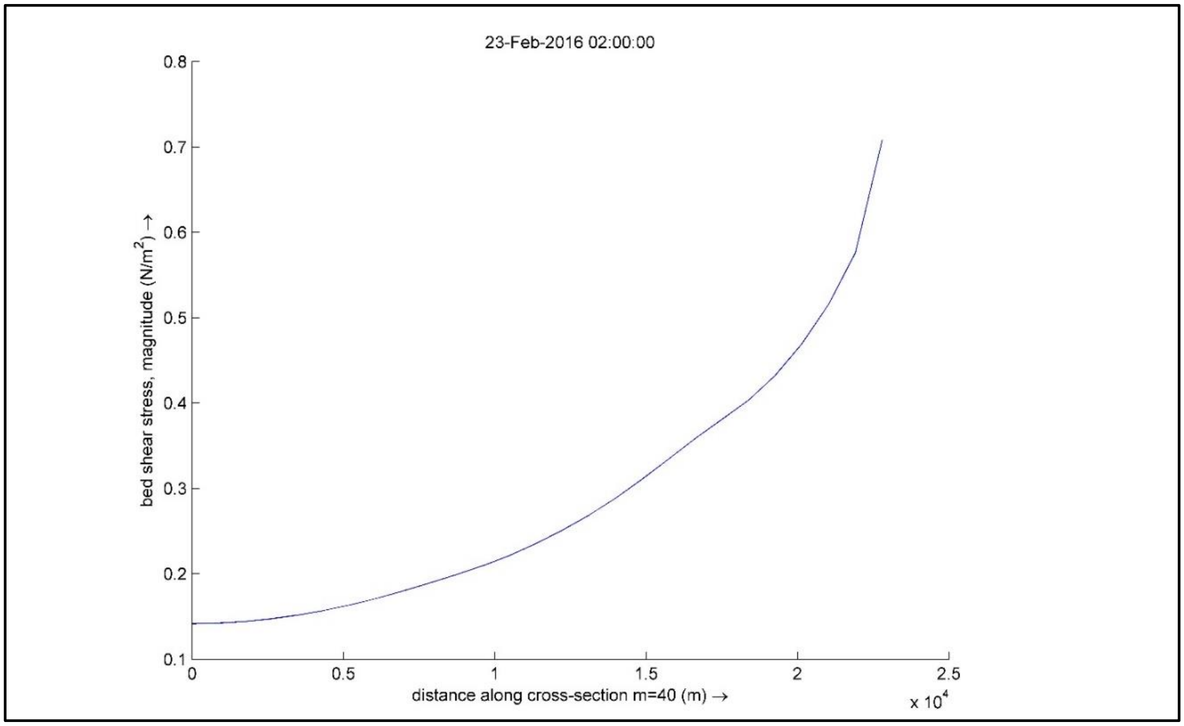


Figure 4.22 Bed shear stress at m=40 for wave angle 240°

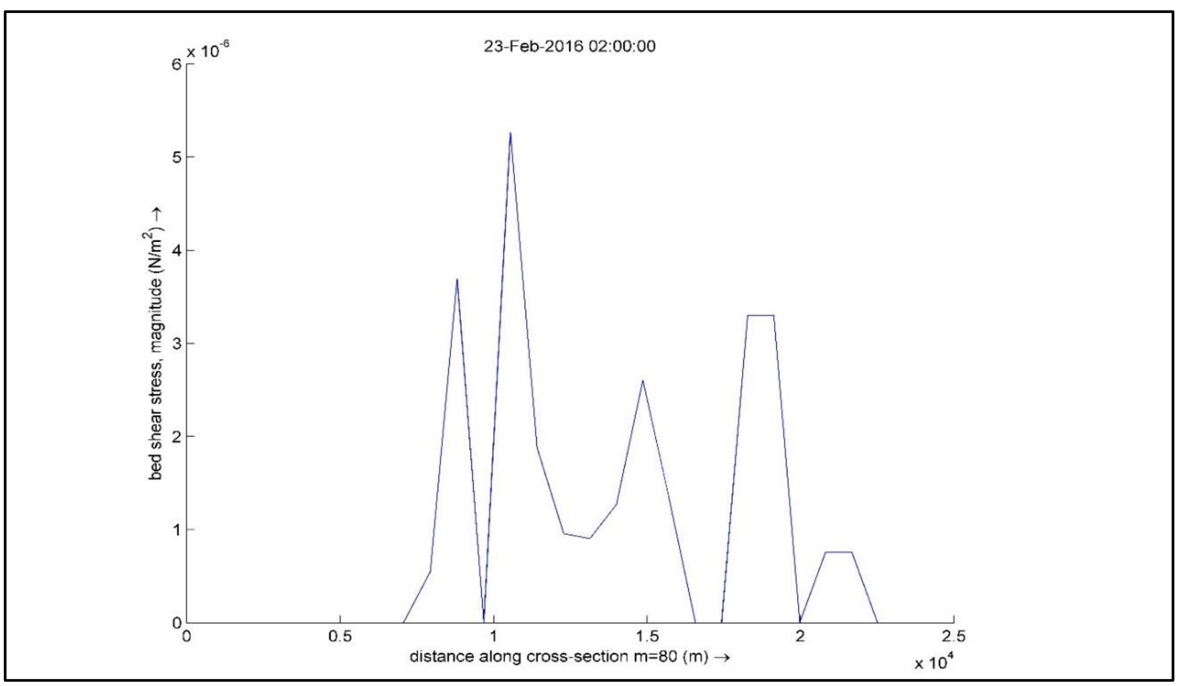


Figure 4.23 Bed shear stress at m=80 for wave angle 240°

### 4.3.3 Sediment Budget

Sediment budget is a concept that applies to sandy and muddy shores. It is only one of three factors (sediment budget, sea level and wave energy) that control most land loss. Sediment budget refers to the balance between sediment added to and removed from the coastal system; in this respect the coastal sediment budget is like a bank account. When more material is added than is removed, there is a surplus of sediment and the shore builds seaward. On the other hand, when more material is removed than is added, there is a deficit in sediment supply and the shore retreats landward. Coastal erosion is a physical expression of a deficit in the sediment budget where nearshore processes remove more material from the shore than is added. Stated another way, coastal recession is the result of insufficient sediment supply compared to sediment removal.

In this research sediment budget is prepared by observing the values of total sediment load at different section from deep sea to shore. Total sediment load is found in $m^3/s/m$ unit. As sand density is 2650 $kg/m^3$ by multiplying it with total sediment load it is found in kg/s/m unit. Thus from deep sea to shore at different cross sections total sediment load is measured and it is found that at deep sea the total amount of sediment carrying is much higher than nearshore. This indicates that the amount of sediment removed is much higher than the amount of sediments added. For wave angle 220° sediment budget is shown below

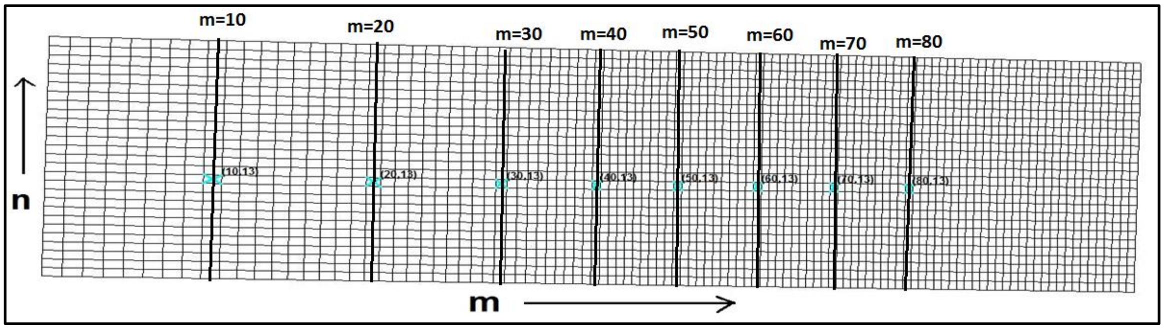


Figure 4.24 Sections along “m” direction taken for observing total sediment load

| Values of “m” from deep sea | Total Sediment Load (kg/s/m) |
|---|---|
| 10 | 2798.609 |
| 20 | 2515.32 |
| 30 | 1273.7 |
| 40 | 769.47 |
| 50 | 170.996 |
| 60 | 0.237 |
| 70 | $1.91 \times 10^{-13}$ |
| 80 | $6.74 * 10^{-11}$ |

Table 4.1 Sediment budget

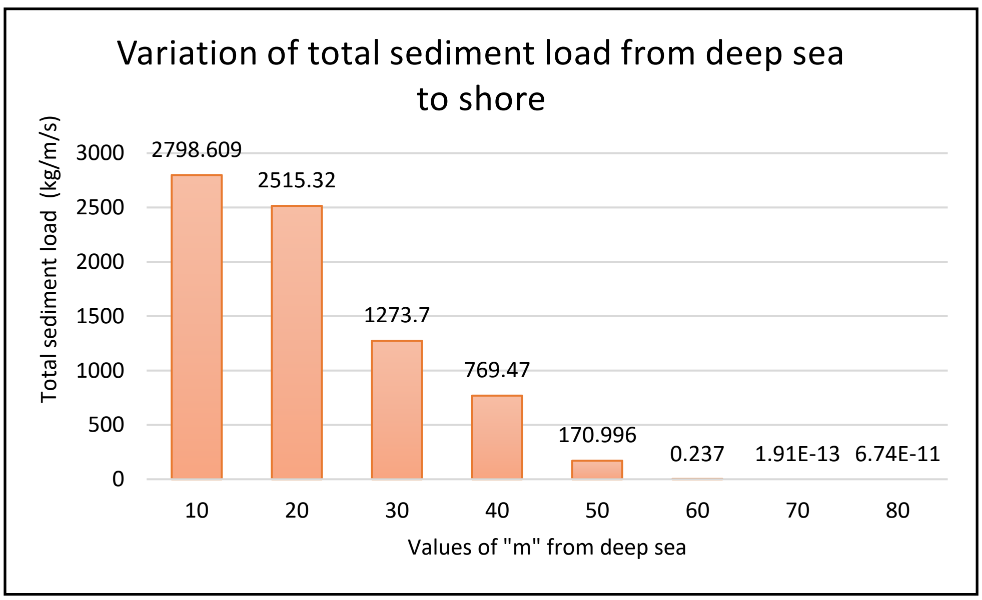


Figure 4.25 Sediment Budget

Total Sediment Load at different sections are shown in the following figures:

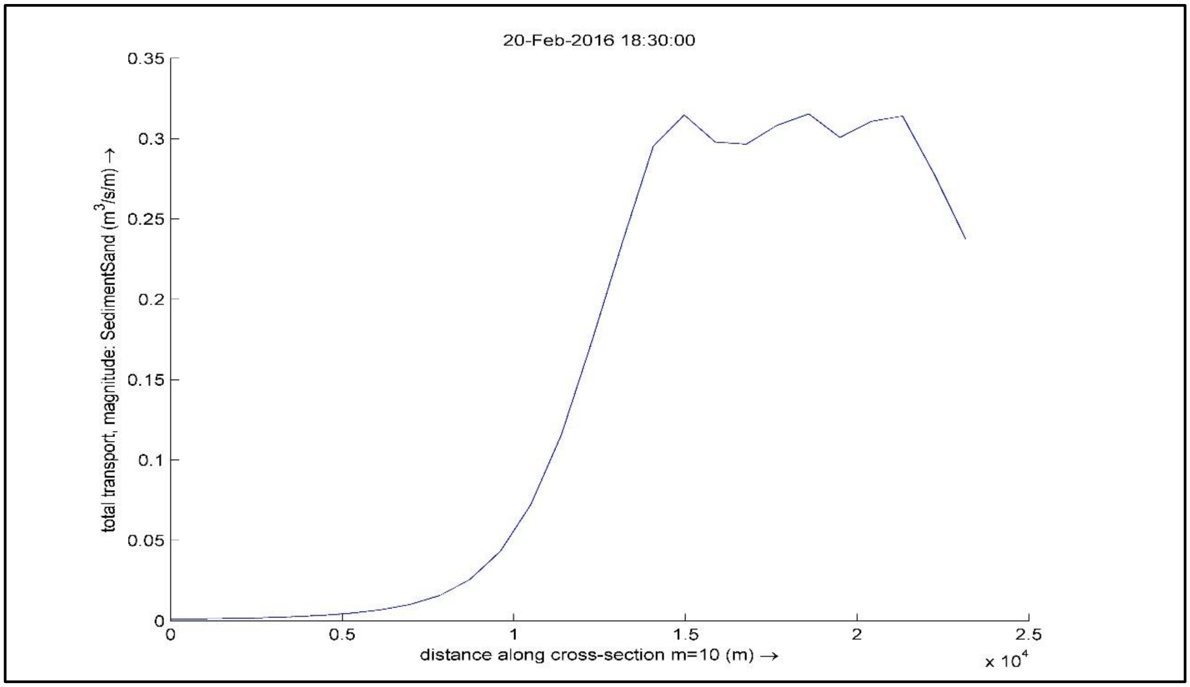


Figure 4.26 Total Sediment load at m=10

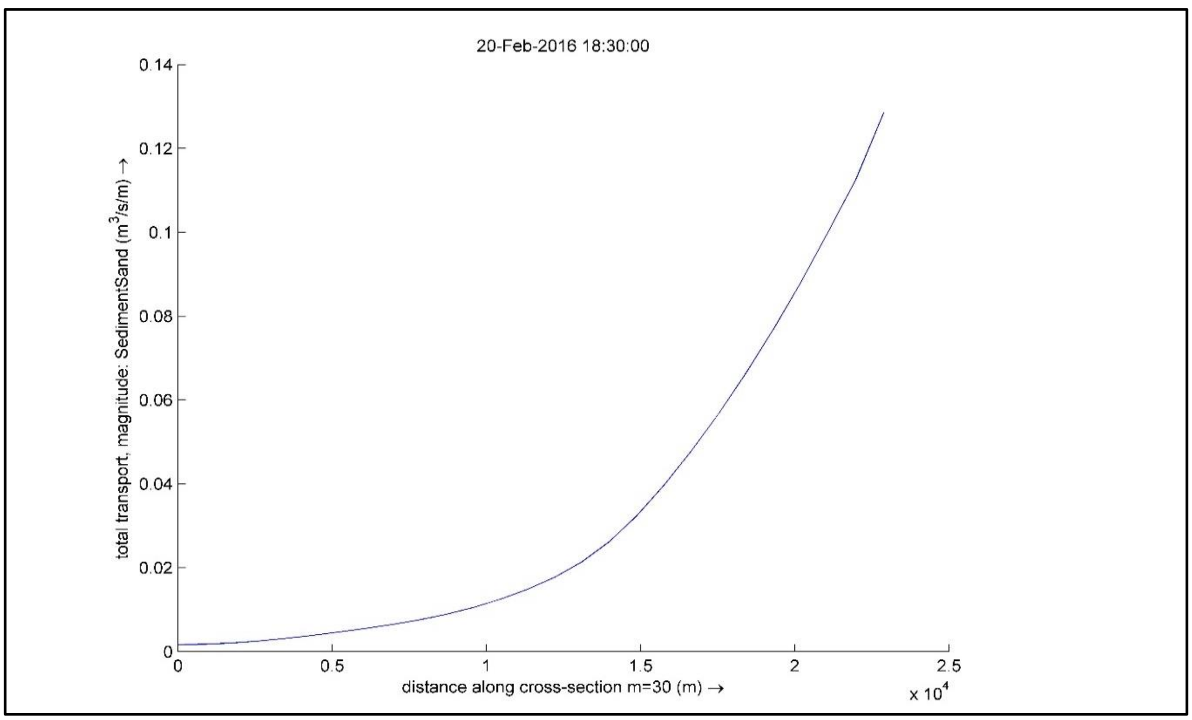


Figure 4.27 Total Sediment load at m=30

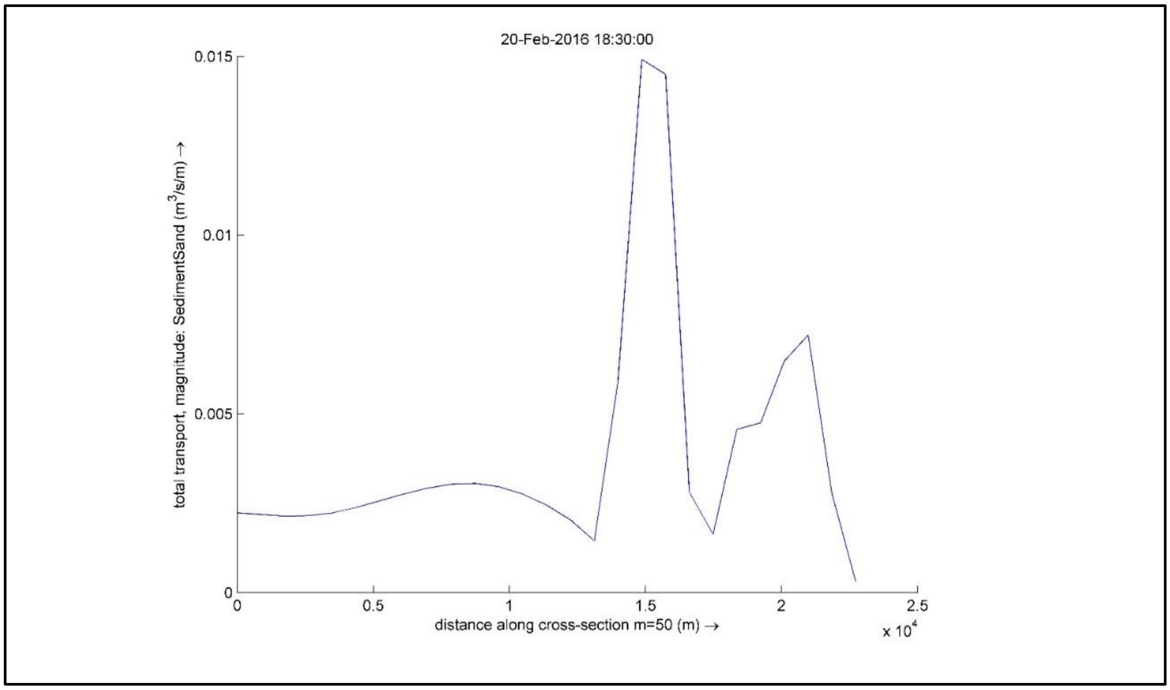


Figure 4.28 Total Sediment load at m=50

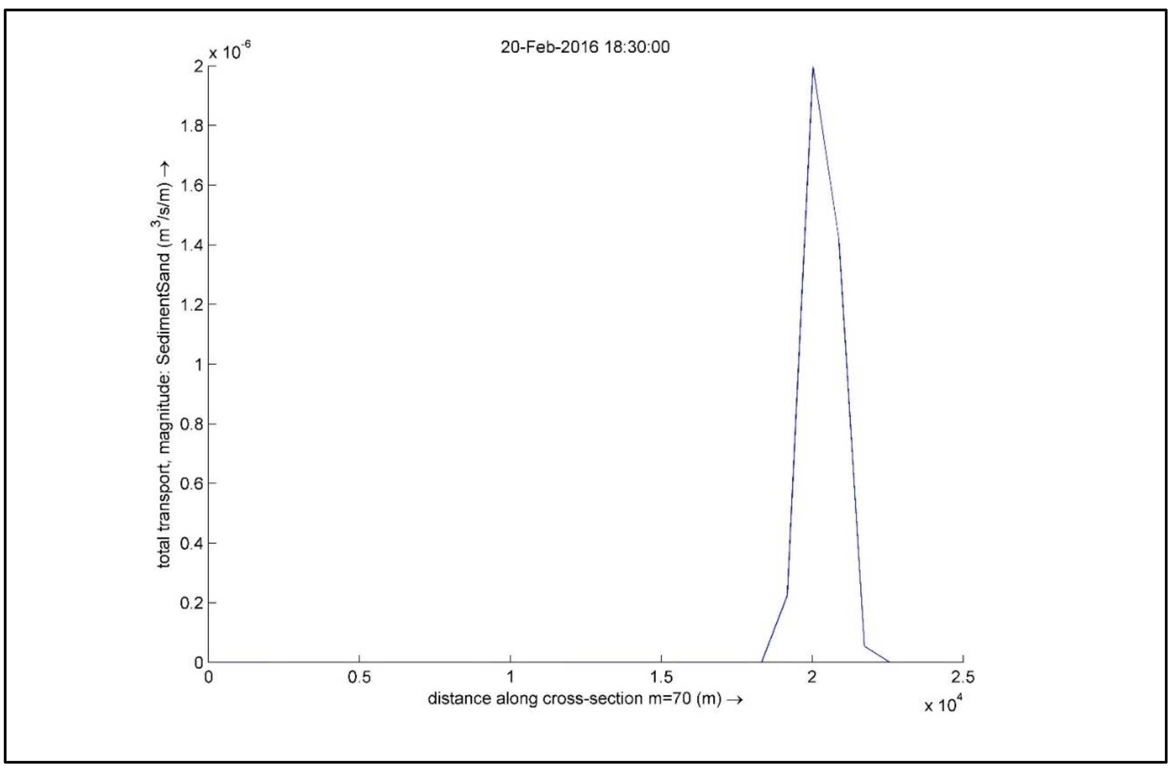


Figure 4.29 Total Sediment load at m=70

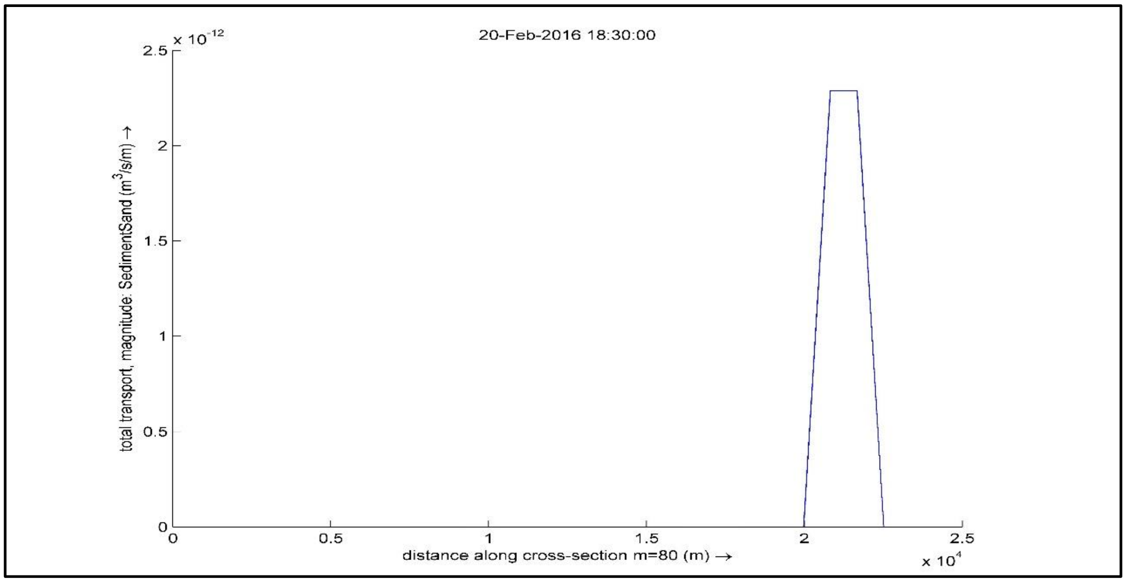


Figure 4.30 Total Sediment load at m=80

# Chapter 5

# Conclusions and Recommendations

## 5.1 General

Morphology is a complex phenomenon which is sometimes very much difficult to predict. To study the hydrodynamic and morphological behavior two dimensional model has been developed of a small strip portion of Bay of Bengal at cox's Bazar using Delft 3D.

The bathymetry data has been collected from IWM which was further incorporated in the model. Curvilinear grids were generated for the whole study area in this infinite difference models which poses higher grid resolution in the area of interest. After generating mesh and bathymetry the model was ready to incorporate initial condition, boundary condition and other properties. The model was run for seven days.

The model was calibrated against the observed wave height and velocity at point 11 in the study area. All these calibrations have shown adequate agreement with the observed values. After calibration it was run to observe the morphological change. Different morphological parameters were adjusted to match the observed and simulated bed level.

## 5.2 Conclusion

The summary of the findings of present study are as follows:

- It is observed that the sediment transport rate is very much related to the velocity. High velocity results in increase in sediment transport which ultimately contributes to the erosion and deposition. From velocity profile, it is found that high velocity occurs after 20 km from the deep sea and about 40 km in the deep sea in the northern part of the area of interest.
- The change in bed level is very abrupt. From the deep sea at northern part of the area of interest has much lower bed elevation.
- Sediment concentration is always high in deep sea and gradually becomes lower while moving towards the shore. As nearshore the wave breaks which results in lower energy and velocity and thus fewer amount of sediment is transported.
- The amount of sediment load added is most of the time is less than the amount of removed. So frequently there is scouring effect at nearshore.

The calibrated and validated model has been used to observe the effects of sediment transport at the area of interest. Most portion of the selected reach is showing same or little erosion/ deposition, short length upstream portion showing greater alternating eroding/depositing nature.

### 5.3 Recommendations

For better understanding of the river behavior and to improve the accuracy of model output following recommendations are suggested.

- The model is set up for only a small strip portion of the Bay of Bengal at Cox's Bazar rather than the whole Bay of Bengal. So there is deviation from observed actual characteristics of wave.
- Sediment transport data is not available in this area. For better approximation of the morphological characteristics sediment data bears immense importance. So should be collected for further development of the model.
- Study may be done with comparatively smaller grid size to define clearly all coastal zones that means all the islands and chars. But the smaller the grid size the higher the simulation time which is a limitation of the model.

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